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6.0 PSD Class II Modeling Procedures – Significant Impact Level Analysis

The dispersion modeling analyses conducted for this project adheres to the EPA "Guideline on Air Quality Models" (GAQM), revised July 2003, and direction received from the VA DEQ Modeling Section. A dispersion modeling protocol delineating all the procedures to be followed was electronically submitted to VA DEQ on January 7, 2010 and was accepted by VA DEQ on March 23, 2010. The following sections present the source data modeled, the procedures for assessing ambient air impacts from the plant's emissions and the standards to which the predicted impacts were compared. Many of the modeling procedures are identical for both PSD Class I and II areas due to the proximity of the Shenandoah National Park to the Project site.

6.1 Background Discussion

The proposed project is a major source with regards to PSD. Per VA DEQ guidance, an air dispersion modeling analysis was required for PM_{10}, $PM_{2.5}$, NO_2 and CO. Modeling analyses performed were evaluated for compliance with applicable PSD increments for these pollutants. In addition, compliance with the National Ambient Air Quality Standards (NAAQS) and 9 VAC 5-60-300 was also evaluated.

Based on the current project design, the natural gas-fired combustion turbines are the primary source of pollutant emissions for the proposed project. Much smaller quantities of criteria pollutants are emitted from the inlet turbine chiller, auxiliary boiler, diesel-fired emergency generator, diesel-fired fire water pump and fuel gas heater. Air dispersion modeling was performed for the combustion turbines, inlet turbine chiller, auxiliary boiler, diesel-fired emergency generator, diesel-fired fire water pump and fuel gas heater.

As will be discussed in the following sections of this document, the dispersion modeling for this project was conducted in a manner that utilized the worst-case operating conditions associated with the ambient temperature range in an effort to predict the highest impact for each averaging period. Maximum predicted impacts from the worst case scenarios were compared to the Significant Impact Levels (SILs), as presented in Table 6-1. For those pollutants which have maximum predicted impacts below the applicable SIL, no additional analyses are necessary since, by definition, the plant would not cause or contribute to a NAAQS violation or an exceedance of a PSD increment for that pollutant.

Table 6-1 Criteria Pollutant Significant Impact Levels for PSD Class II Areas

Pollutant	Averaging Time				
	Annual ($\mu g/m^3$)	24-hour ($\mu g/m^3$)	8-hour ($\mu g/m^3$)	3-hour ($\mu g/m^3$)	1-hour ($\mu g/m^3$)
NO_2	1	-	-	-	-
CO	-	-	500	-	2,000
PM_{10}	1	5	-	-	-
Source: 9 VAC 5-80-1715 B.1					

6.2 Source Data

6.2.1 Normal Operations

The air dispersion modeling analysis was conducted with emission rates and flue gas exhaust characteristics (flow rate and temperature) that are expected to represent the worst-case parameters among the range of possible values for the combustion turbines considered for the proposed project. Since turbine emission rates and flue gas characteristics for a given turbine load vary as a function of ambient temperature, data was derived for the following ambient temperatures and load scenarios for the proposed project:

<u>Combined-Cycle Combustion Turbines – Natural Gas Operations</u>

- 4 operating loads (100% w/ Duct Firing, 100%, 75%, 60%)
- 3 ambient temperatures (100°F, 59°F, 0°F)

A summary of the combined-cycle exhaust data and emission rates for the PSD-regulated pollutants for each ambient temperature and operating load during natural gas combustion is provided in Table 6-2. The proposed combustion turbines are rated at a maximum capacity of 3,496 MMBtu/hr at 0°F (2,996 MMBtu/hr rating for just the combustion turbines and 500 MMBtu/hr rating for the duct burners).

Based on current project design parameters, Dominion intends to apply for a permit that will allow unrestricted annual operation (8,760 hours per year) of each combined-cycle combustion turbine.

In order to conservatively calculate ground-level concentrations, a composite “worst-case” set of emission parameters was used in the modeling. For each combined-cycle operating load, the highest pollutant-specific emission rate coupled with the lowest exhaust temperature and exhaust flow rate was selected. Table 6-3 summarizes the worst-case emission parameters for the proposed combined-cycle combustion turbines operating loads firing natural gas.

Table 6-4 provides the stack parameters and criteria pollutant emission rates for the inlet turbine chillers, auxiliary boiler, and the fuel gas heater. Since the performance data for the auxiliary equipment are not affected by ambient conditions, only one set of parameters was modeled (e.g., stack parameters and emission rates associated with 100% load). The inlet turbine chillers, auxiliary boiler and the fuel gas heater are expected to operate 8,760 hours per year.

Table 6-2 Source Parameters and Criteria Pollutant Emission Rates(1) Natural Gas-Fired Combined-Cycle Combustion Turbine Operation

Scenario(2)	Heat Input (MMBtu/hr)	Stack Height (ft)	Stack Dia. (ft)	Exit Temp. (°F)	Exit Velocity (fps)	Maximum Hourly Emissions (lb/hr)(3)				
						NO_X	CO	PM_{10}	$PM_{2.5}$	SO_2
100% load with Duct Firing @ 0°F	***3,496***	175.0	22.0	195.80	70.44	***25.32***	***17.41***	***21.16***	***21.16***	(4)
100% load with Duct Firing @ 59°F	3,108	175.0	22.0	***191.20***	62.73	22.51	16.12	19.09	19.09	(4)
100% load with Duct Firing and Inlet Chiller @ 59°F	3,170	175.0	22.0	192.30	63.96	22.96	16.33	19.42	19.42	(4)
100% load with Duct Firing @ 100°F	2,841	175.0	22.0	195.30	***57.83***	20.57	15.24	17.66	17.66	(4)
100% load with Duct Firing and Inlet Chiller @ 100°F	3,170	175.0	22.0	199.30	64.65	22.96	16.33	19.42	19.42	(4)
100% load @ 0°F	***2,996***	175.0	22.0	202.10	70.64	***21.70***	***9.91***	***15.51***	***15.51***	(4)
100% load @ 59°F	2,608	175.0	22.0	***197.70***	62.89	18.89	8.62	13.51	13.51	(4)
100% load with Inlet Chiller @ 59°F	2,670	175.0	22.0	198.40	64.09	19.34	8.83	13.83	13.83	(4)
100% load @ 100°F	2,341	175.0	22.0	199.60	***57.74***	16.95	7.74	12.12	12.12	(4)
100% load with Inlet Chiller @ 100°F	2,670	175.0	22.0	205.10	64.74	19.34	8.83	13.83	13.83	(4)
75% load @ 0°F	***2,302***	175.0	22.0	194.60	56.78	***16.67***	***7.61***	***11.92***	***11.92***	(4)
75% load @ 59°F	2,052	175.0	22.0	***191.50***	52.08	14.86	6.78	10.63	10.63	(4)
75% load @ 100°F	1,874	175.0	22.0	192.90	***48.32***	13.57	6.20	9.70	9.70	(4)
60% load @ 0°F	***1,966***	175.0	22.0	187.20	47.01	***14.24***	***6.50***	***10.18***	***10.18***	(4)
60% load @ 59°F	1,770	175.0	22.0	***185.00***	43.60	12.82	5.85	9.17	9.17	(4)
60% load @ 100°F	1,627	175.0	22.0	185.70	***41.16***	11.78	5.38	8.43	8.43	(4)

(1) Data provided by Dominion.

(2) Data presented are for four operating loads/conditions at three ambient temperatures

(3) Hourly emissions reflect operation of a combined-cycle combustion turbine firing pipeline natural gas only.

(4) Emission estimates indicate that SO_2 will not be subject to PSD review. Therefore, an SO_2 modeling analysis was not performed.

Table 6-3 Worst Case Data for Proposed Natural Gas-Fired Combined-Cycle Combustion Turbine Operation

		Value[1]			
Load (%)		**100 w/ Duct Firing**	**100**	**75**	**60**
Stack Height (ft)		175.0	175.0	175.0	175.0
Stack Diameter (ft)		22.0	22.0	22.0	22.0
Exit Temperature (°F)		191.20	197.70	191.50	185.00
Exit Velocity (ft/sec)		57.83	57.74	48.32	41.16
Heat Input (MMBtu/hr)		3,496	2,996	2,302	1,966
Pollutant Emissions Per Combustion Turbine(lb/hr)	**SO_2**	(2)	(2)	(2)	(2)
	PM_{10} 24 hour	21.16	15.51	11.92	10.18
	PM_{10} Annual[3]	19.38	19.38	19.38	19.38
	$PM_{2.5}$ 24 Hour	21.16	15.51	11.92	10.18
	$PM_{2.5}$ Annual[3]	19.38	19.38	19.38	19.38
	NO_X Annual[3]	24.18	24.18	24.18	24.18
	CO	17.41	9.91	7.61	6.50

(1) The values in the table represent the worst-case stack parameters and the emission rates for the four operating loads taken from the Table 3-6 (bold and italicized)

(2) Emission estimates indicate that SO_2 was not subject to PSD review. Therefore, an SO_2 modeling analysis was not performed.

(3) Annual emissions based on the worst case emissions across all normal operations or normal operating plus SUSD. The following worst case annual emissions will be annualized and modeled across all operating loads:

- PM_{10} – 84.89 tpy / 8760*2000 = 19.38 lb/hr
- NO_x – 105.90 tpy / 8760*2000 = 24.18 lb/hr

Table 6-4 Source Parameters and Criteria Pollutant Emission Rates(1) For the Auxiliary Equipment

Source ID	Stack Height (ft)	Stack Diameter (ft)	Exit Temp. (°F)	Exit Velocity (fps)	Hourly Emissions (lb/hr)				
					NO_X	CO	PM_{10}	$PM_{2.5}$	SO_2
Inlet turbine chiller1(2)									
CHLR1	42.88	12.00	70.00	24.50	--	--	5.99E-03	1.84E-05	--
Inlet turbine chiller2(2)									
CHLR2	42.88	12.00	70.00	24.50	--	--	5.99E-03	1.84E-05	--
Inlet Turbine chiller3(2)									
CHLR3	42.88	12.00	70.00	24.50	--	--	5.99E-03	1.84E-05	--
Auxiliary Boiler									
AUX_BLR	115.00	3.00	300.00	61.00	0.97	3.26	0.44	0.44	(3)
Fuel Gas Heater									
FGH	45.00	3.33	300.00	32.00	0.57	1.92	0.39	0.39	(3)

(1) Data provided by Dominion.

(2) The hourly emissions represent the emissions from a single cell of the 6-cell inlet turbine chiller.

(3) Emission estimates indicate that SO_2 was not subject to PSD review. Therefore, an SO_2 modeling analysis was not performed.

The emergency diesel generator and fire-water pump engine are expected to operate one (1) hour per week per unit and 52 hours per year per unit under non-emergency conditions (operability testing). Therefore, for modeling associated with these units, the modeled emission rates were annualized based on the 52 hours per year. The short- term emission rates were also normalized based on 1 hour per week, but this hour was conservatively modeled such that it can be any hour of the year. Table 6-5 provides the stack parameters and criteria pollutant emission rates for the emergency generator and the fire water pump. Please note that the project will accept a permit condition for each unit that limits non-emergency use to 52 hours per year and total use (non-emergency plus emergency) to 500 hours per year.

Table 6-5 Source Parameters and Criteria Pollutant Emission Rates(1) For the Emergency Equipment

Source ID	Stack Height (ft)	Stack Diameter (ft)	Exit Temp. (°F)	Exit Velocity (fps)	Hourly Emissions (lb/hr)(2)							
					NO_X	CO		PM_{10}		$PM_{2.5}$		SO_2
						1-hour	8-hour	24-hour	Annual	24-hour	Annual	
Diesel-Fired Emergency Generator												
DSL_GEN	115.0	1.23	987.00	135.00	0.14	12.62	1.58	0.06	0.0086	0.06	0.0086	(3)
Diesel-Fired Fire Water Pump Engine												
FWP	20.00	0.44	845.00	135.00	0.012	1.72	0.22	0.0083	0.0012	0.0083	0.0012	(3)

(1) Data provided by Dominion.

(2) Emissions rates were normalized based on the following equations:

Short-term Averaging Period – Emission Rate *(1/ Hours of Averaging Period)

Annual Averaging Period - Emission Rate * 52 hours per year / 8,760

(3) Emission estimates indicate that SO_2 was not subject to PSD review. Therefore, an SO_2 modeling analysis was not performed.

6.2.2 Startup/Shutdown Operations

For the modeling analysis, it has been assumed that the turbines will startup in sequence; therefore, no more than one turbine can startup at any one time. Short-term emissions resulting from start-up/shutdown operations for the proposed turbines are based on warm starts and cold starts. Each warm start is expected to last 101 minutes and each cold start is expected to last 252 minutes before the turbine is operating at minimum normal operation. To add a measure of conservatism to the emission calculations, it has been assumed that the turbines will reach their maximum potential emissions (100% load with duct burners) immediately after the startup (warm/cold).

Short-term emissions for the turbines were calculated based on the maximum of either startup/shutdown emissions or a mix of startup/shutdown and normal operation emissions (if the startup period is shorter than the total averaging period). For the averaging periods for which the duration of the startup is shorter than the averaging period, the remaining time (in the averaging period) for the turbines were assumed to be associated with worst-case load conditions (100% with duct burners). Table 6-6 presents a summary of the startup emissions for each of the short- term averaging periods for the proposed turbines.

As directed by VA DEQ, a startup modeling analysis was performed for all the criteria pollutants subject to PSD review. For averaging periods where the duration of the startup is shorter than the averaging period, a separate startup stack and normal operation stack was modeled. Table 6-7 presents the stack parameters that were used in the analysis for the short-term pollutants.

Table 6-6 Short-term Averaging Period Startup Summary[1]

	Offline	Start	Normal	Total	Start	Normal	Total
	min	min	min	min	lb	lb	lb
CO 1-hour							
Turbine 1	0	60	0	60	813.90	0	813.90
Turbine 2	60	0	0	60	0	0	0
Turbine 3	60	0	0	60	0	0	0
Startup Total							813.90
Normal Operation Total[2]							52.23
CO 8-hour							
Turbine 1	0	252	228	480	2205.30	66.16	2271.46
Turbine 2	252	101	127	480	804.20	36.85	841.05
Turbine 3	353	101	26	480	804.20	7.54	811.74
Startup Total							3924.25
Normal Operation Total[2]							417.84
PM_{10} 24-hour							
Turbine 1	0	252	1188	1440	23.30	418.97	442.27
Turbine 2	252	101	1087	1440	8.90	383.35	392.25
Turbine 3	353	101	986	1440	8.90	347.73	356.63
Startup Total							1191.15
Normal Operation Total[2]							1523.52
$PM_{2.5}$ 24-hour							
Turbine 1	0	252	1188	1440	23.30	418.97	442.27
Turbine 2	252	101	1087	1440	8.90	383.35	392.25
Turbine 3	353	101	986	1440	8.90	347.73	356.63
Startup Total							1191.15
Normal Operation Total[2]							1523.52
NO_X 24-hour[3]							
Turbine 1	0	252	1188	1440	115.10	501.34	616.44
Turbine 2	252	101	1087	1440	77.00	458.71	535.71
Turbine 3	353	101	986	1440	77.00	416.09	493.09
Startup Total							1645.24
Normal Operation Total[2]							1823.04
SO_2 24-hour[3]							
Turbine 1	0	252	1188	1440	1.28	19.40	20.68
Turbine 2	252	101	1087	1440	0.49	17.75	18.24
Turbine 3	353	101	986	1440	0.49	16.10	16.59
Startup Total							55.52
Normal Operation Total[2]							70.56

(1) Startup emissions presented are for the proposed combustion turbines.
(2) Normal operation emissions correspond to those for 100% load with duct burners
(3) NO_X 24-hour and SO_2 24-hour calculated for determining if additional Class I visibility modeling is needed for startup.

Table 6-7 Stack parameters and modeled emissions rates

Operating Mode	Exit Velocity (fps)	Exit Temp (^{0}F)	CO 1-hour (lb/hr)			CO 8–hour (lb/hr)			$PM_{10}/PM_{2.5}$ 24–hour (lb/hr)		
			Turbine 1	Turbine 2	Turbine 3	Turbine 1	Turbine 2	Turbine 3	Turbine 1	Turbine 2	Turbine 3
Startup											
Cold Start(1),(2)	37.92	185.00	813.90	NA	NA	275.66	NA	NA	0.97	NA	NA
Warm Start(1),(2)	37.93	185.00	NA	NA	NA	NA	100.53	100.53	NA	0.37	0.37
Normal Operation(3)	57.83	191.20	NA	NA	NA	8.27	4.61	0.94	17.46	15.97	14.49

(1) Average exhaust velocity during startup, provided by vendor and/or Dominion
(2) Lowest exit temperature for 60% load from performance data provided by vendor and/or Dominion
(3) Exit velocity and temperature for the 100% load with duct burner from performance data provided by vendor and/or Dominion

Annual emissions resulting from start-up/shutdown operations for the proposed turbines are based on 174 hot starts/year, 15 warm starts/year, and 6 cold starts/year. For each hot start, the turbines are assumed to be offline for at least 4 hours. For each warm start, the turbines are assumed to be offline for at least 40 hours, and for each cold start, the turbines are assumed to be offline for at least 72 hours. Under this operating scenario, it is estimated that the turbines will be offline for 1,728 hours/year.

Annual emissions for the proposed turbines were calculated based on the maximum of either 8,760 hr/year of continuous operation or a mix of continuous operation and the maximum number of startup/shutdown events. Table 6-8 provides a summary of the startup emissions for the annual averaging periods for the proposed combustion turbines.

Table 6-8 Annual Averaging Period Startup Summary

Operating Mode	hr/yr	NO_x		PM_{10}	
		lb/hr	tpy	lb/hr	tpy
Startup					
Offline	1,728	0.00	0	0.00	0
Without duct burning	811	21.70	8.8	15.51	6.3
With duct burning	6,000	25.32	76.0	21.16	63.5
Hot start	125	83.86	5.2	5.72	0.4
Warm start	25	45.74	0.6	5.29	0.1
Cold start	25	27.40	0.3	5.55	0.1
Shutdown	46	102.00	2.3	5.57	0.1
TOTALS	8,760		**93.2**		**70.4**

Normal Operation					
100% load					
Without duct burning	2,760	21.70	29.9	15.51	21.4
With duct burning	6,000	25.32	76.0	21.16	63.5
TOTALS	8,760		**105.9**		**84.9**
100% load w/o duct burners	8,760	21.70	**95.0**	15.51	**67.9**

The emissions from the startup/shutdown were annualized and conservatively modeled with an averaged stack exit velocity (averaged over all the possible startups and shutdown scenario) and lowest stack exit temperature from the 60% load. The worst-case emissions from the normal operations were annualized and conservatively modeled across all operating loads using the load specific exit velocity and exit temperature (see table 6-9).

Table 6-9 Stack parameters and modeled emissions rates for Annual Pollutants

Operating Mode	Exit Velocity (fps)	Exit Temp (^{0}F)	NO_X Annual (lb/hr)			$PM_{10}/PM_{2.5}$ Annual (lb/hr)		
			Turbine 1	Turbine 2	Turbine 3	Turbine 1	Turbine 2	Turbine 3
Startup[(1),(2)]	32.375	184.90	1.93	1.93	1.93	0.14	0.14	0.14
Normal Operation[(3)]								
100% with Duct Burner	57.83	191.20	19.35	19.35	19.35	15.93	15.93	15.93
100%	57.74	197.71	19.35	19.35	19.35	15.93	15.93	15.93
75%	48.32	191.50	19.35	19.35	19.35	15.93	15.93	15.93
60%	41.16	185.00	19.35	19.35	19.35	15.93	15.93	15.93

(1) Average exhaust velocity across all types of startups and shutdown, provided by the vendor and/or Dominion
(2) Lowest exit temperature for 60% load from performance data provided by vendor and/or Dominion
(3) Exit velocity and temperature from performance data provided by vendor and/or Dominion

6.3 AERMOD Model Applicability and Model Options

The United States Environmental Protection Agency (USEPA) adopted a final rule (Federal Register November 9, 2005) that replaced the Industrial Source Complex (ISC) model with AERMOD (AERMIC MODel) (USEPA 2004). The rule became effective on December 9, 2005, and the ISC model was phased out as of December 9, 2006.

Therefore, this modeling analysis utilized the AERMOD dispersion model to evaluate air quality impacts from the proposed project. The AERMOD model was developed by the AERMIC work group (the American Meteorological Society/EPA Regulatory Model Improvement Committee) and was intended to incorporate improved understanding of planetary boundary layer (PBL) meteorology into air dispersion calculations. The current version of AERMOD is 09292 and includes the Prime (Plume

Rise Model Enhancement) building downwash algorithms. The AERMOD modeling system consists of two preprocessors and the dispersion model. AERMET is the meteorological preprocessor component and AERMAP is the terrain pre-processor component that characterizes the terrain and generates receptor elevations along with critical hill heights for those receptors.

6.4 Good Engineering Practice Stack Height Analysis

A Good Engineering Practice (GEP) stack height analysis was performed based on the proposed project design to determine the potential for building-induced aerodynamic downwash for the proposed combustion turbine stacks. The analysis procedures described in EPA's Guidelines for Determination of Good Engineering Practice Stack Height (EPA, 1985), Stack Height Regulations (40 CFR 51), and current Model Clearinghouse guidance was used.

The GEP formula height is based on the observed phenomenon of disturbed atmospheric flow in the immediate vicinity of a structure resulting in higher ground level concentrations closer to the building than would otherwise occur. It identifies the minimum stack height at which significant aerodynamic downwash is avoided. The GEP formula stack height, as defined in the 1985 final regulations, is calculated from:

$H_{GEP} = H_{BLDG} + 1.5L$
Where:

- HGEP is the maximum GEP stack height
- HBLDG is the height of the nearby structure, and
- L is the lesser dimension (height or projected width) of the nearby structure

Both the height and width of the structure are determined from the frontal area of the structure projected onto a plane perpendicular to the direction of the wind. In all instances, the GEP stack height is based on the plane projections of any nearby building which result in the greatest justifiable height. For purposes of the GEP analysis, "nearby" refers to the "sphere of influence," defined as five times the height or width of the building, whichever is less, downwind from the trailing edge of the structure. In the case where a stack is not influenced by nearby structures, the maximum GEP stack height is defined as 65 meters.

The EPA's Building Profile Input Program (BPIP-Version 04274) version that is appropriate for use with PRIME algorithms in AERMOD was used to incorporate downwash effects in the model. The building dimensions of each structure were input in BPIPPRM program to determine direction specific building data. PRIME addresses the entire structure of the wake, from the cavity immediately downwind of the building, to the far wake. Figure 6-1 shows the buildings and source locations considered in the modeling analysis.

6.5 Receptor Grid and AERMAP Processing

The Class II grid consisted of receptors spaced 25 m apart along the fence line. A spacing of 50 m was used for the receptors beyond the fence line and extending out to 1 km from the fence line. Beyond 1 km from the fence line, a spacing of 100 m was used up to 2.5 km from the plant. Between 2.5 and 5 km, a spacing of 500 m was used. Between 5 and 10 km, a spacing of 1000 m was used. Beyond 10 km, a spacing of 2000 m was used. No receptors within the Shenandoah National Park were included in the Class II analysis. Receptors with 1000-m spacing were placed at the boundary

of the Class I Area extending out to 20 km. The receptor grid used in the modeling analysis was based on NAD 83 datum and in zone 17. The extent of this grid was sufficient to capture maximum impacts in the Class II area analysis. Figures 6-2 and 6-3 show the far-field and near field Cartesian receptor grid respectively considered for the modeling analysis.

As mentioned in the protocol, the receptor grid was refined around the receptor with the maximum concentration, if it was outside the 50-meter spacing grid. This was done to ascertain that none of the receptors with impacts potentially exceeding the SILs were missed. The maximum impacts for CO 1-hour and 8-hour, NO_X annual and PM_{10} annual were found to be within the 50-meter spacing and therefore, no refined receptors were added to the Cartesian grid. A 2-km by 2-km grid with 50-meter spacing receptors centered on the receptor with maximum impact across all operating loads for each year was added to the above-mentioned discrete Cartesian grid for the PM_{10} 24-hour averaging period. Figure 6-4 shows the refined receptor grid considered for the PM_{10} 24-hour modeling analysis.

Receptor height scales at each receptor location (used in AERMOD) were developed by AERMAP (version 09040), the terrain preprocessor for AERMOD. AERMAP was run using the 1/3 arc second (~10 m resolution) National Elevation Data (NED) for the proposed project location which was downloaded from the United States Geological Services (USGS) website (http://seamless.usgs.gov/index.php). As per the AERMAP User's Guide (USEPA, 2004), the domain was sufficiently large enough to accommodate all the significant nodes such that all terrain features that exceed a 10% elevation slope from any given receptor were considered. Figure 6-5 shows the modeling domain to demonstrate this. The full report generated by AERMAP is provided in Appendix F and is included with the modeling files on the DVD.

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Figure 6-1 Source Locations and Main Building Structures Included in GEP-BPIP PRIME Analysis

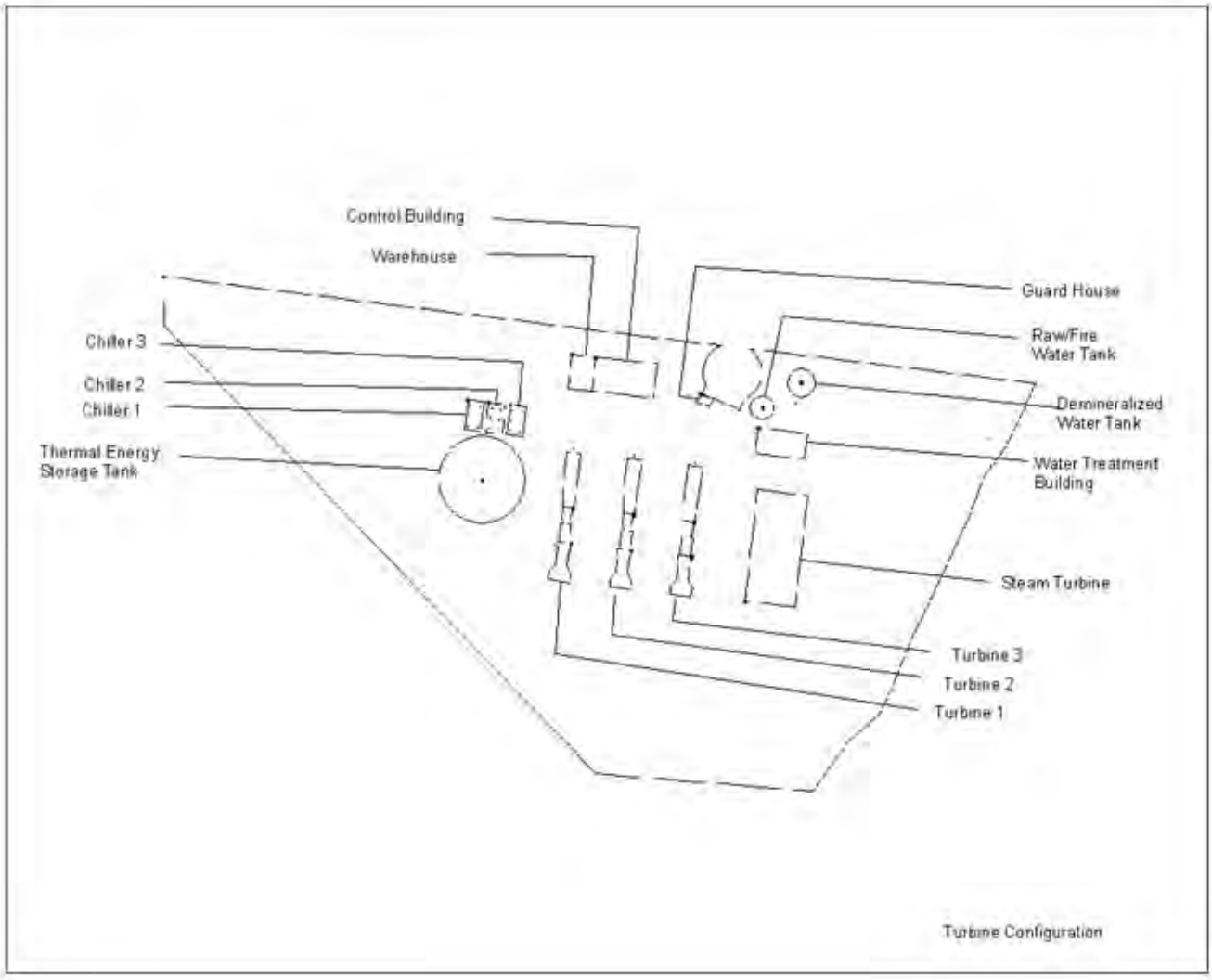


Figure 6-2 20-km Receptor Grid for SIL AERMOD Modeling Analysis

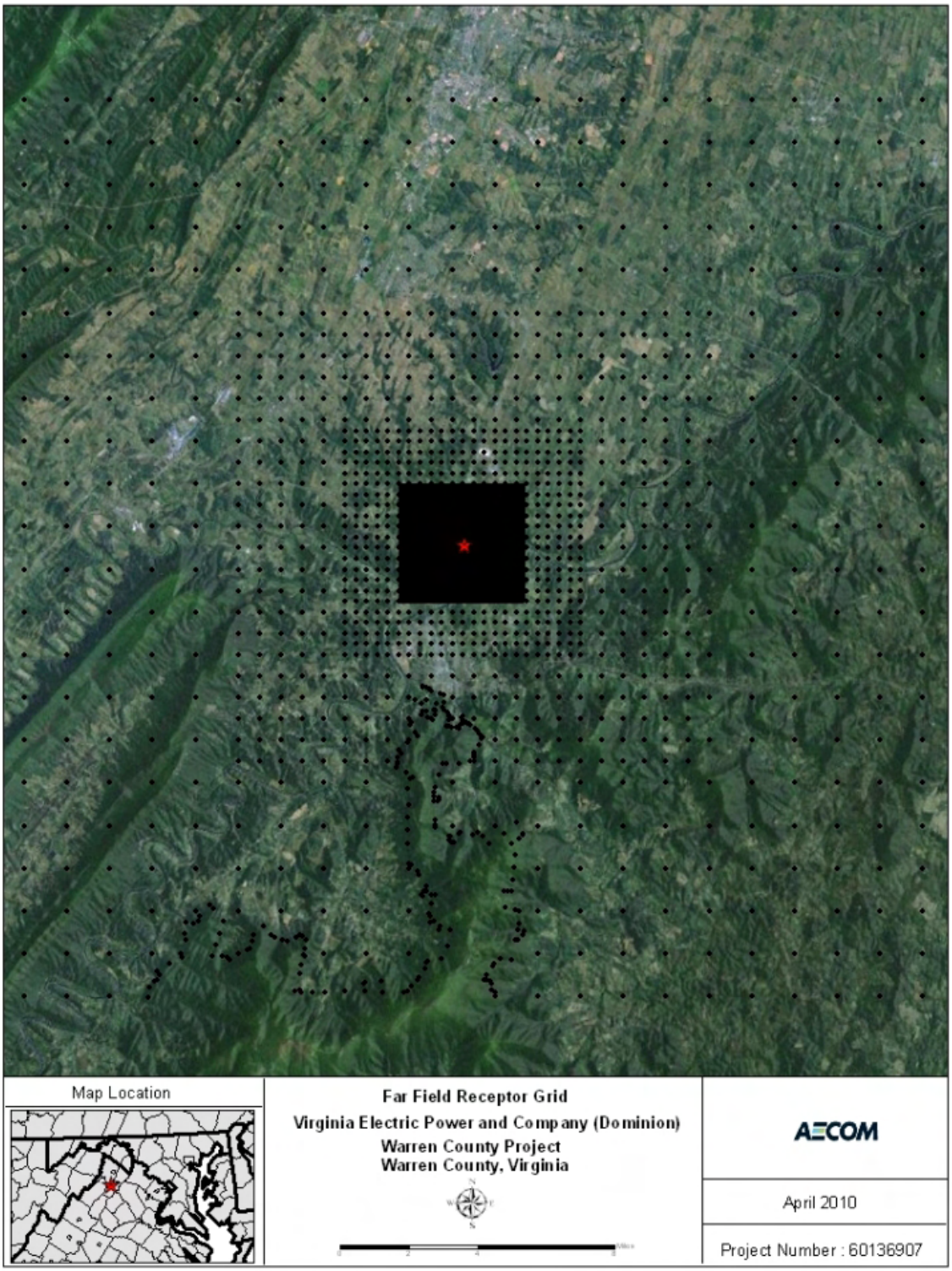


Figure 6-3 Near-Field Receptor Grid for SIL AERMOD Modeling Analysis

Figure 6-4 Refined Receptor Grid for PM_{10} 24-hour SIL AERMOD Modeling Analysis

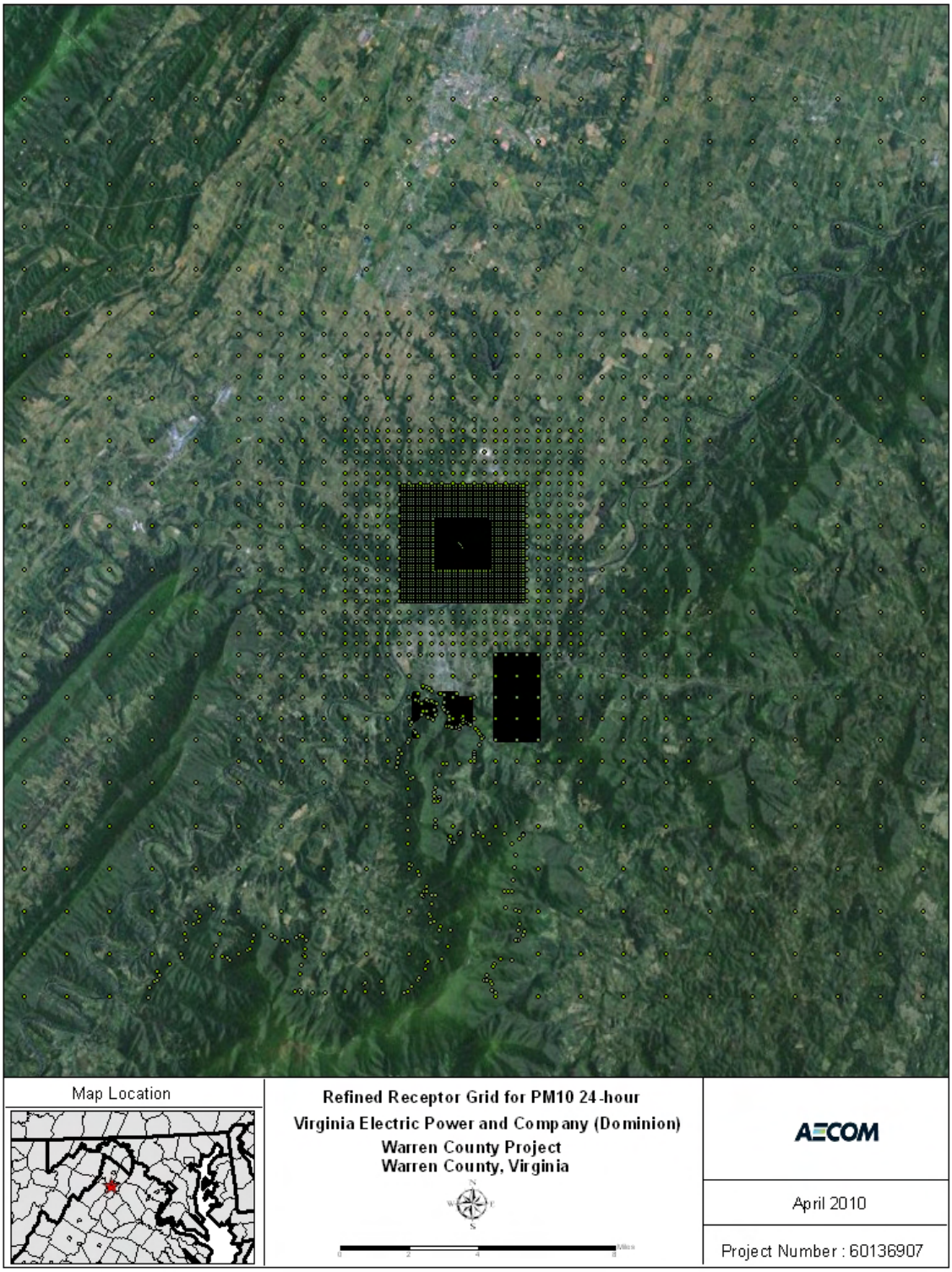
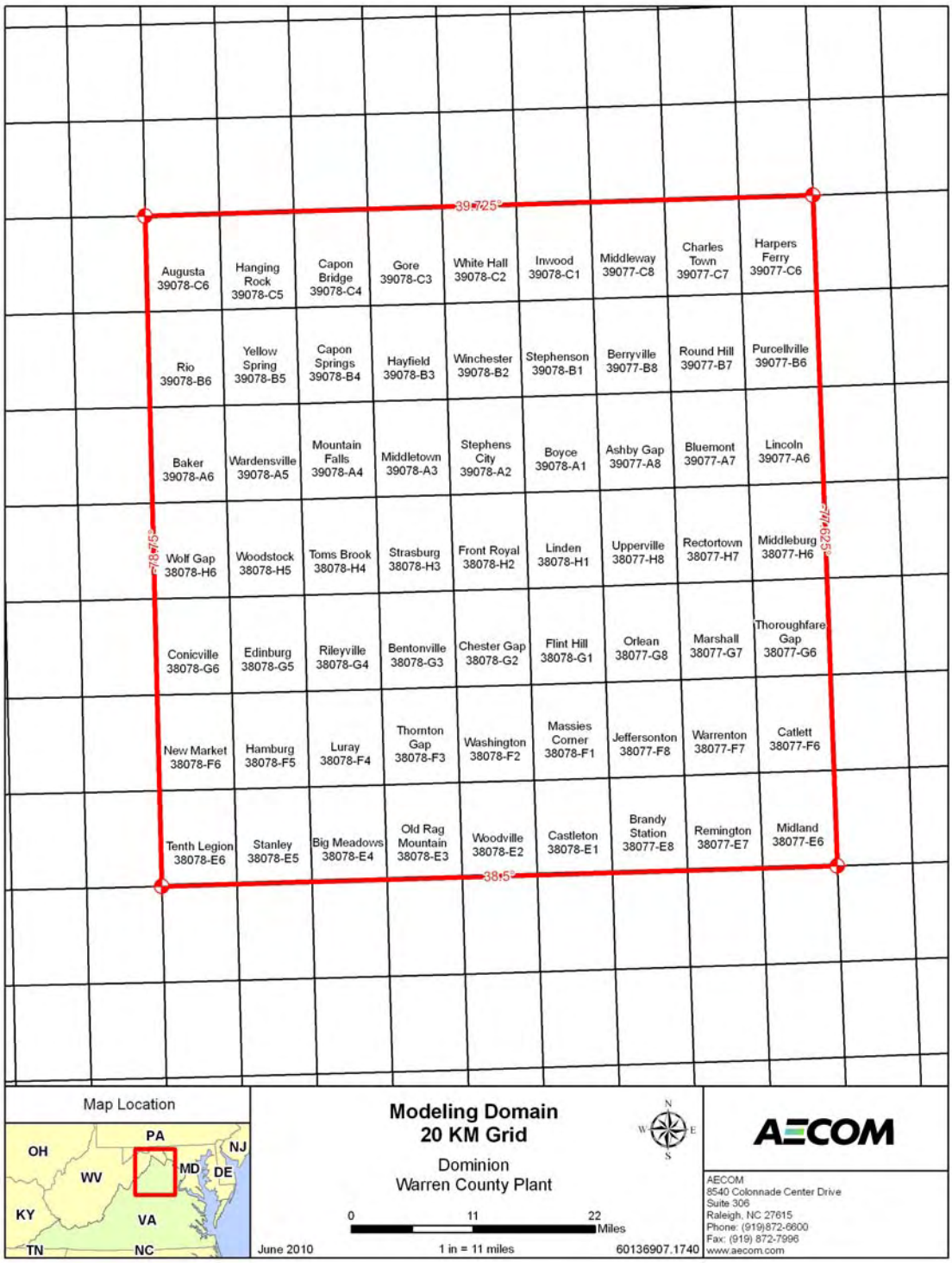


Figure 6-5 Modeling Domain Used in the Class II Modeling Analysis



6.6 Meteorological Data Processing

For the previous permitting of the Project at this same site, VA DEQ and the National Park Service (NPS) agreed to the use of five years of National Weather Service (NWS) data from Dulles International Airport. For this project, we retained the use of the same database. Detailed justification of the database has been provided in the modeling protocol. Figure 6-6 shows the locations of the Project relative to the airport location. Both sites are located in relatively flat areas, with the overall orientation of distant terrain features consistent from southwest to northeast.

Five years of hourly surface meteorological data were processed with AERMET, the meteorological preprocessor for AERMOD. The meteorological data required for input to AERMOD was created with the latest version of AERMET (06341), the meteorological preprocessor, which utilized hourly surface observations from Dulles International Airport along with concurrent upper air data from Sterling, VA. Table 6-10 gives site locations and information on these data sets. The surface data (wind direction, wind speed, temperature, sky cover, and relative humidity) was measured at 6.1 m above ground level. AERMET creates two output files for input to AERMOD:

- SURFACE: a file with boundary layer parameters such as sensible heat flux, surface friction velocity, convective velocity scale, vertical potential temperature gradient in the 500-meter layer above the planetary boundary layer, and convective and mechanical mixing heights. Also provided are values of Monin-Obukhov length, surface roughness, albedo, Bowen ratio, wind speed, wind direction, temperature, and heights at which measurements were taken.
- PROFILE: a file containing multi-level meteorological data with wind speed, wind direction, temperature, sigma-theta (σ_θ) and sigma-w (σ_w) when such data are available. For this application involving representative data from the nearest NWS station, the profile file will contain a single level of wind data (6.1 meters) and the temperature data (2 meters).

In modeling AERMET, the observed airport hourly wind direction was randomized. Missing morning soundings account for only about 2% of the days, so these were not filled in by interpolation or substitution.

AERMET requires specification of site characteristics including surface roughness (z_o), albedo (r), and Bowen ratio (B_o). These parameters were developed according to the guidance provided by US EPA in the recently revised AERMOD Implementation Guide (AIG) (EPA, 2009).

The revised AIG provides the following recommendations for determining the site characteristics:

1. The determination of the surface roughness length should be based on an inverse distance weighted geometric mean for a default upwind distance of 1 kilometer relative to the measurement site. Surface roughness length may be varied by sector to account for variations in land cover near the measurement site; however, the sector widths should be no smaller than 30 degrees.
2. The determination of the Bowen ratio should be based on a simple un-weighted geometric mean (i.e., no direction or distance dependency) for a representative domain, with a default domain defined by a 10-km by 10-km region centered on the measurement site.

3. The determination of the albedo should be based on a simple un-weighted arithmetic mean (i.e., no direction or distance dependency) for the same representative domain as defined for Bowen ratio, with a default domain defined by a 10-km by 10-km region centered on the measurement site.

Sectors used to define the meteorological surface characteristics for the airport site are shown in Figure 6-7.

The AIG recommends that the surface characteristics be determined based on digitized land cover data. US EPA has developed a tool called AERSURFACE that can be used to determine the site characteristics based on digitized land cover data in accordance with the recommendations from the AIG discussed above. AERSURFACE incorporates look-up tables of representative surface characteristic values by land cover category and seasonal category. AERSURFACE was applied with the instructions provided in the AERSURFACE User's Guide.

The current version of AERSURFACE (Version 08009) supports the use of land cover data from the USGS National Land Cover Data 1992 archives[3] (NLCD92). The NLCD92 archive provides data at a spatial resolution of 30 meters based upon a 21-category classification scheme applied over the continental U.S. The AIG recommends that the surface characteristics be determined based on the land use within 1 km surrounding the site where the surface meteorological data were collected, as shown in Figure 6-8 with selected sectors. The selection of the land use types assigned in the NLCD92 database was reviewed and one erroneous land use assignment was corrected for input to AERSURFACE, as discussed in Appendix E.

In AERSURFACE, the various land cover categories are linked to a set of seasonal surface characteristics. As such, AERSURFACE requires specification of the seasonal category for each month of the year. The following five seasonal categories are supported by AERSURFACE, with the applicable months of the year specified for this site.

1. Midsummer with lush vegetation (May-September).
2. Autumn with un-harvested cropland (October-November).
3. Late autumn after frost and harvest, or winter with no snow (December-February)
4. Winter with continuous snow on ground (none).
5. Transitional spring with partial green coverage or short annuals (March-April).

For Bowen ratio, the land use values are linked to three categories of surface moisture corresponding to average, wet and dry conditions. The surface moisture condition for the site may vary depending on the meteorological data period for which the surface characteristics will be applied. AERSURFACE applies the surface moisture condition for the entire data period. Therefore, if the surface moisture condition varies significantly across the data period, then AERSURFACE can be applied multiple times to account for those variations. As recommended in AERSURFACE User's Guide, the surface moisture condition for each month was determined by comparing precipitation for the data period of

[3] http://edcftp.cr.usgs.gov/pub/data/landcover/states/

data that was processed to the 30-year climatological record, selecting “wet” conditions if precipitation was in the upper 30th-percentile, “dry” conditions if precipitation was in the lower 30th-percentile, and “average” conditions if precipitation was in the middle 40th-percentile. The 30-year precipitation data set used in this modeling was taken from Dulles International Airport, VA.

The monthly designations of surface moisture input to AERSURFACE are summarized in Table 6-11.

Table 6-10 AERSURFACE Bowen Ratio Condition Designations

Month	1988	1989	1990	1991	1992
January	Average	Average	Wet	Average	Average
February	Average	Average	Dry	Dry	Average
March	Dry	Average	Average	Wet	Average
April	Dry	Average	Wet	Dry	Average
May	Wet	Wet	Average	Dry	Average
June	Dry	Wet	Dry	Wet	Average
July	Wet	Wet	Wet	Average	Wet
August	Average	Dry	Wet	Dry	Dry
September	Dry	Average	Dry	Average	Wet
October	Dry	Wet	Wet	Dry	Average
November	Average	Average	Average	Average	Wet
December	Dry	Dry	Wet	Wet	Wet

Table 6-11 Meteorological Data Used in Running AERMET

Met Site	Latitude	Longitude	Base Elevation (m)	Data Source	Data Format
Dulles Airport, VA	38.934	-77.447	88	NCDC	CD-144
Sterling, VA	38.983	-77.467	85	WebMet	6201FB

Figure 6-6 Location of Project Site Relative to Dulles International Airport

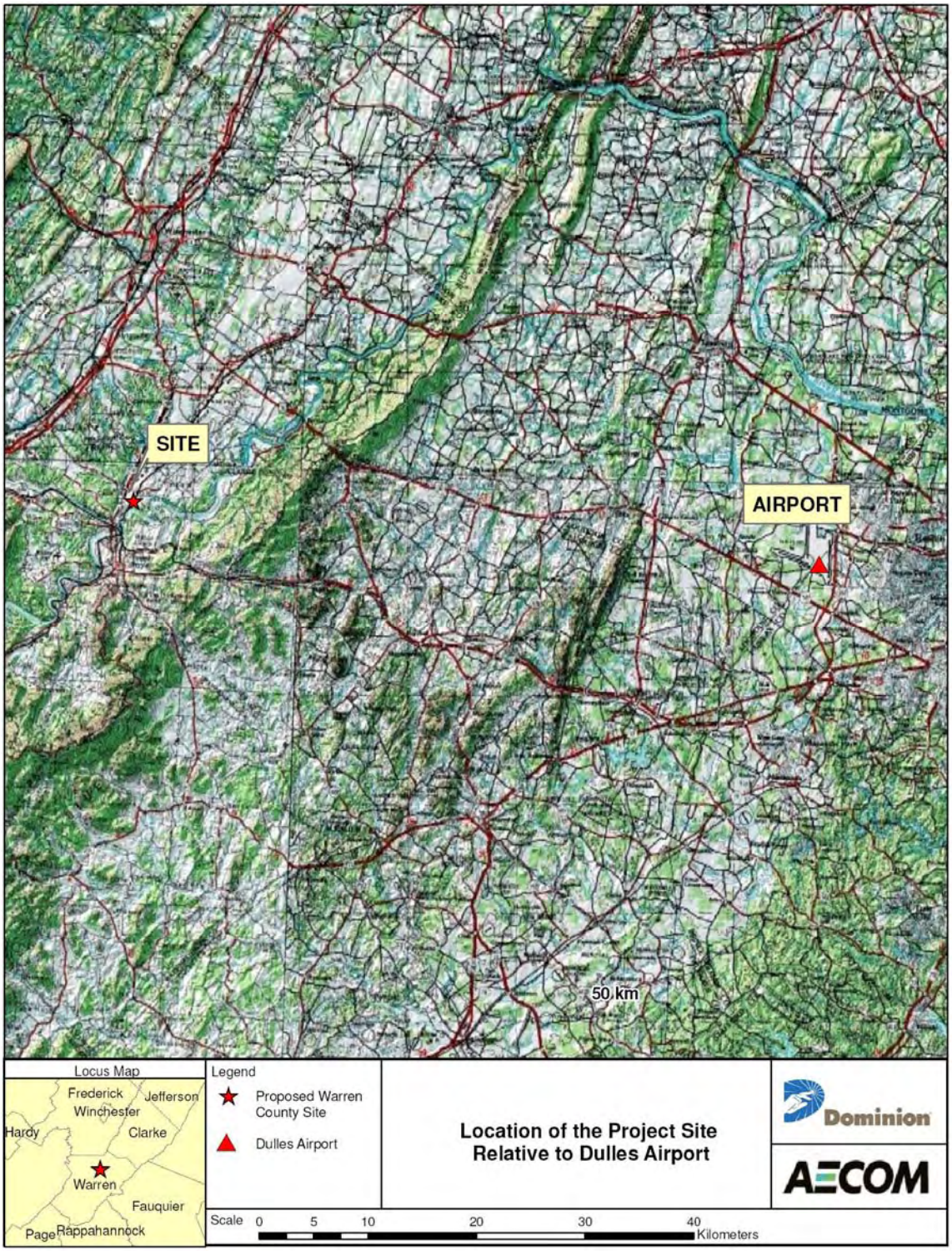


Figure 6-7 Sectors Used for Surface Characteristics at Dulles International Airport

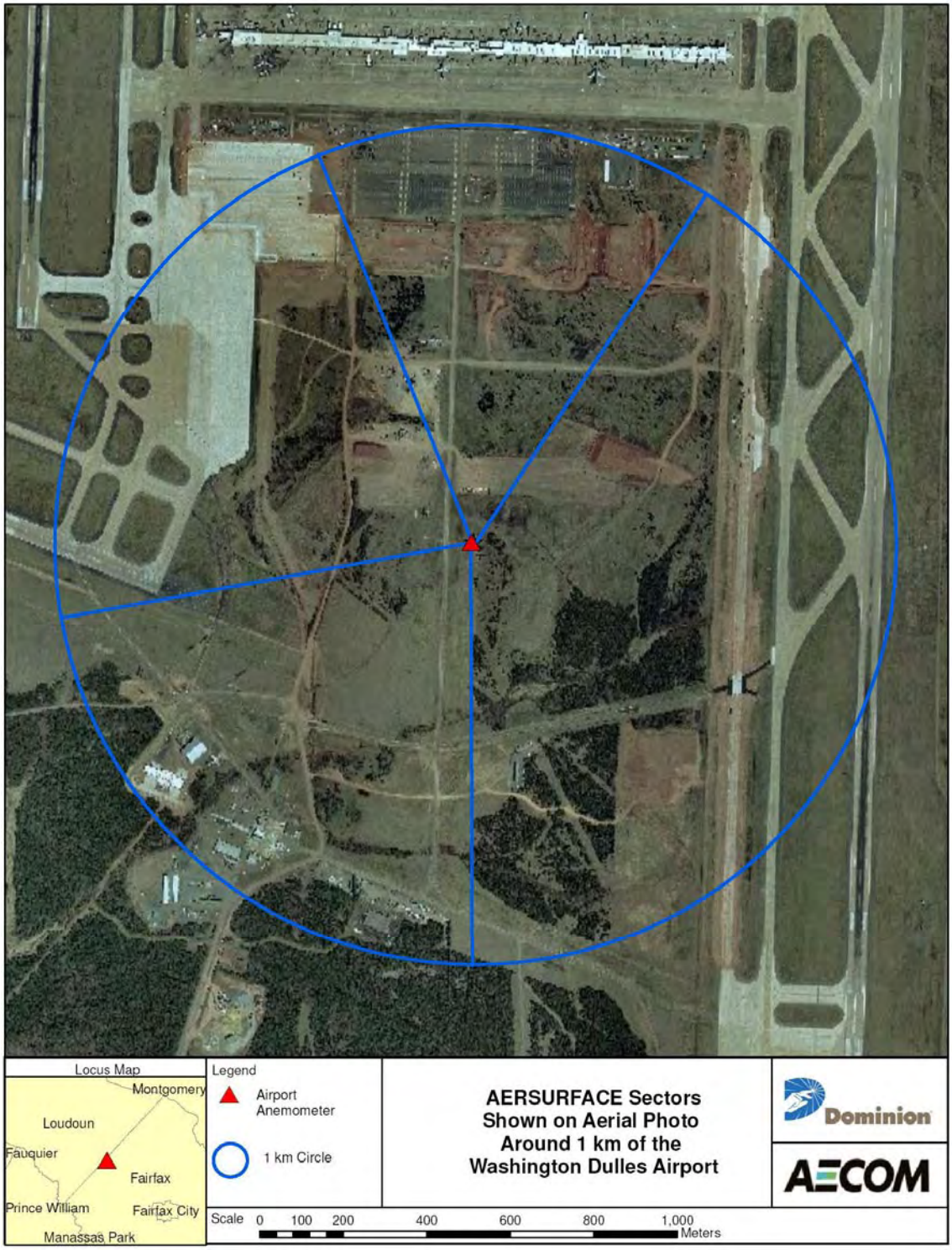
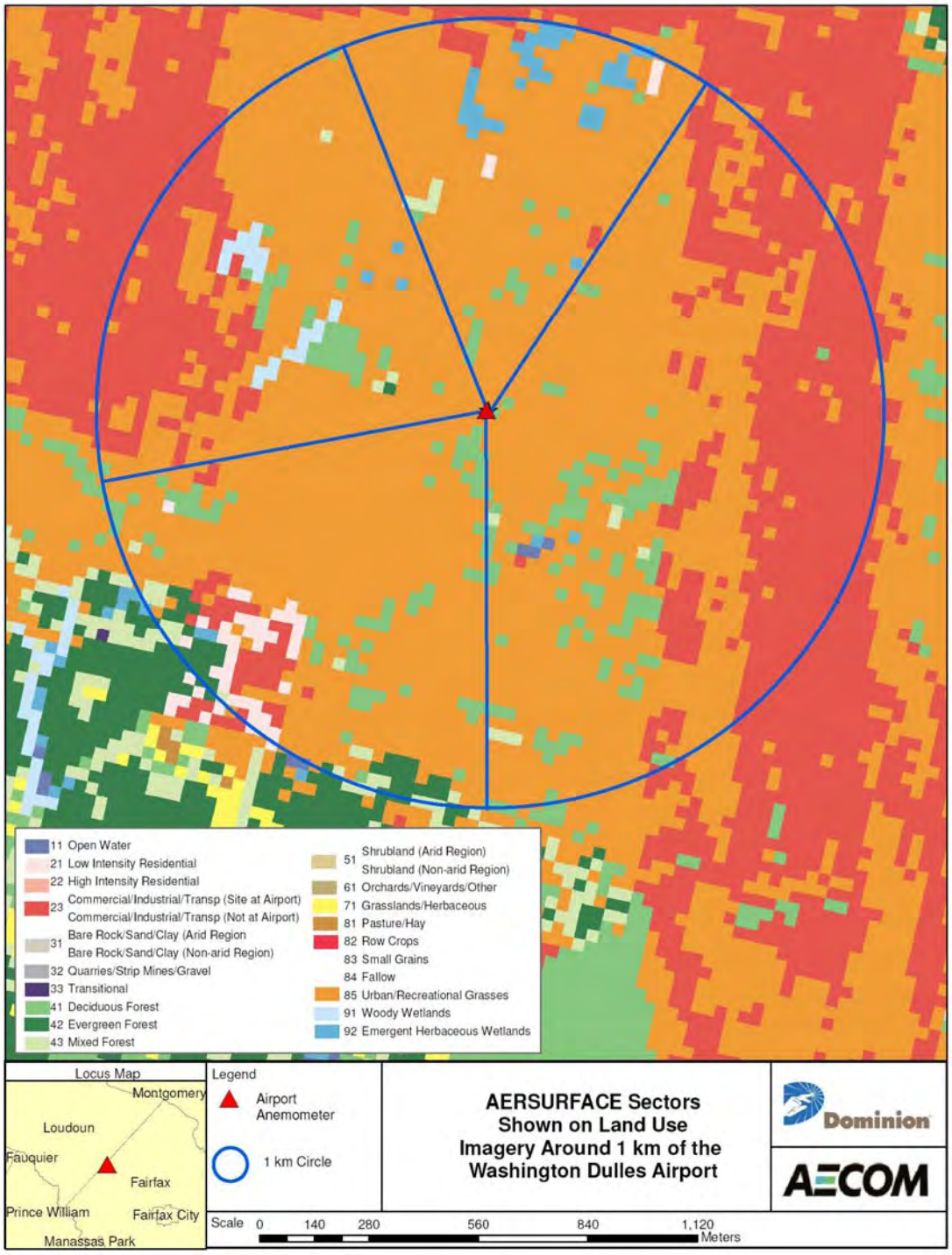


Figure 6-8 1-km Radius for Dulles International Airport With Surface Roughness Sectors Shown on Land Use Imagery



6.7 Compliance with Class II Air Quality Standards

The predicted impacts from the air quality impact analysis, presented in Section 7, for the proposed project were compared to the appropriate standards as summarized in the tables listed below:

Table 6-1 Criteria Pollutant Significant Impact Levels
Table 6-12 PSD Increments
Table 6-13 Ambient Air Quality Standards

Please note, a compliance analysis for the $PM_{2.5}$ NAAQS is provided in Section 10. In addition, a compliance analysis for 1-hour NO_2 was provided to VA DEQ under separate cover.

Table 6-12 PSD Increments for PSD Class II Areas

Pollutant and Averaging Period	Class II Increment ($\mu g/m^3$)
Nitrogen Dioxide	
Annual Arithmetic Average	25
Particulate Matter (PM-10)	
Annual Geometric Average	17
24-Hour	30
Source: 9 VAC 5-80-1635	

Table 6-13 Ambient Air Quality Standards for PSD Class II Areas

Pollutant	Averaging Period(2)	National AAQS(1)	
		Primary	Secondary
CO	8-hour	10,000	--(3)
	1-hour	40,000	--(3)
NO_2	Annual	100	100
PM_{10}	24-hour	150	150
$PM_{2.5}$	24-hour	35	35
	Annual	15	15

(1) All standards in this table are expressed in $\mu g/m^3$.

(2) To attain the standards the following conditions must be met:

- CO 1-hour- Not to be exceeded more than once per year.
- CO 8-hour- Not to be exceeded more than once per year.
- NO_2 Annual – Never to exceed the standard
- PM_{10} 24-hour - Not to be exceeded more than once per year on average over 3 years.
- $PM_{2.5}$ 24-hour - To attain this standard, the 3-year average of the 98th percentile of 24-hour concentrations at each population-oriented monitor within an area must not exceed the standard.
- $PM_{2.5}$ Annual - To attain this standard, the 3-year average of the weighted annual mean $PM_{2.5}$ concentrations from single or multiple community-oriented monitors must not exceed the standard.

(3) No ambient standard for this pollutant and/or averaging period

Source: 9 VAC 5 Chapter 30

6.8 Pre-Construction Ambient Monitoring Waiver

The highest predicted pollutant impacts from the proposed project were compared to the monitoring exemption levels (9 VAC 5-80-1695 E) as listed in Table 6-8. As noted in Section 7, predicted impacts are below these monitoring exemption levels. Since VOC emissions for the proposed project exceed 100 tons per year, ambient air quality data from the nearest monitor, Luray Caverns Airport, has been included in Appendix F for the VA DEQ's approval.

Table 6-14 PSD Monitoring Threshold Concentrations

Pollutant	Averaging Period	Threshold Concentration ($\mu g/m^3$)
CO	8-hour	575
NO_2	Annual	14
PM/PM_{10}	24-hour	10
O_3	N/A	(1)

(1) Exempt if VOC emissions are less than 100 tons per year (tpy)

Based on the modeling data and Virginia ambient air quality data, which is "representative of the area of concern," Dominion requests a waiver from the requirement for a pre-construction ambient monitoring program from the VA DEQ's Air Quality Assessment Group (AQAG).

6.9 Ambient Air Quality Data

Preliminary modeling has indicated that the project will have significant impacts in Class II areas for PM_{10} 24-hour and 24-hour and annual $PM_{2.5}$ (based on the lowest proposed SILs) and in Class I areas for annual NO_2, 24-hour and annual PM_{10}, and 24-hour and annual $PM_{2.5}$ (based on the lowest proposed SILs). As such, a table of representative background air quality data has been prepared.

Ambient air quality data are used to represent the contribution to total ambient air pollutant concentrations from non-modeled sources. The following discussion demonstrates that available regional monitoring data for a recent 3-year period satisfies these requirements.

Local ambient air monitoring stations were researched to identify the background air quality concentrations representative of the proposed project site. Table 1 summarizes the monitor locations and background air quality concentrations obtained from EPA's AirData website. Figure 6-9 shows the locations of the monitors relative to the Warren County project site. The Warren County project site is a located on a rural site about 5 km northeast of Front Royal, VA, surrounded mainly by agricultural lands with some residential and compact residential areas a few km to the south.

A summary of the selected monitors is as follows:

- PM_{10}: The proposed PM_{10} monitor is located in Front Royal, VA, only 5 km southwest of the Warren County project site. At this distance, this monitor should be very representative of the ambient background level surrounding the project site.
- NO_2: The project did not have a significant impact for annual average NO_2. For the 1-hour NO_2 modeling, the Virginia DEQ provided a representative, conservative regional background concentration from the Rockingham County monitor (40 ppb). This monitor is located about 50 km to the southwest of the project site.
- $PM_{2.5}$: The proposed $PM_{2.5}$ monitor is located in Luray, VA. It is located approximately 44 km to the southwest of the proposed project site. Luray is a rural town with predominantly agricultural land-use surrounding it, similar to the proposed project site. The population of Luray is approximately 5,000. The proposed $PM_{2.5}$ monitor is the second closest monitor to the Warren County project site. The closest $PM_{2.5}$ monitor is located 22 miles north, in the town of Ridgeway, WV. Although the Luray monitor is a little further from the Warren County site than the Ridgeway monitor, the land-use surrounding the Luray monitor is more representative of the proposed project site.

Ultimately, the project showed insignificant impacts for annual NO_2 in Class II area, hence the only background values used from those proposed in the above table were for 1-hour NO_2, PM_{10} and $PM_{2.5}$ for each pollutant's respective NAAQS modeling. For Class I modeling, significant impacts were predicted within Shenandoah, for NO_2 and PM_{10}, but the proposed project showed compliance with the PSD increments for both of these pollutants.

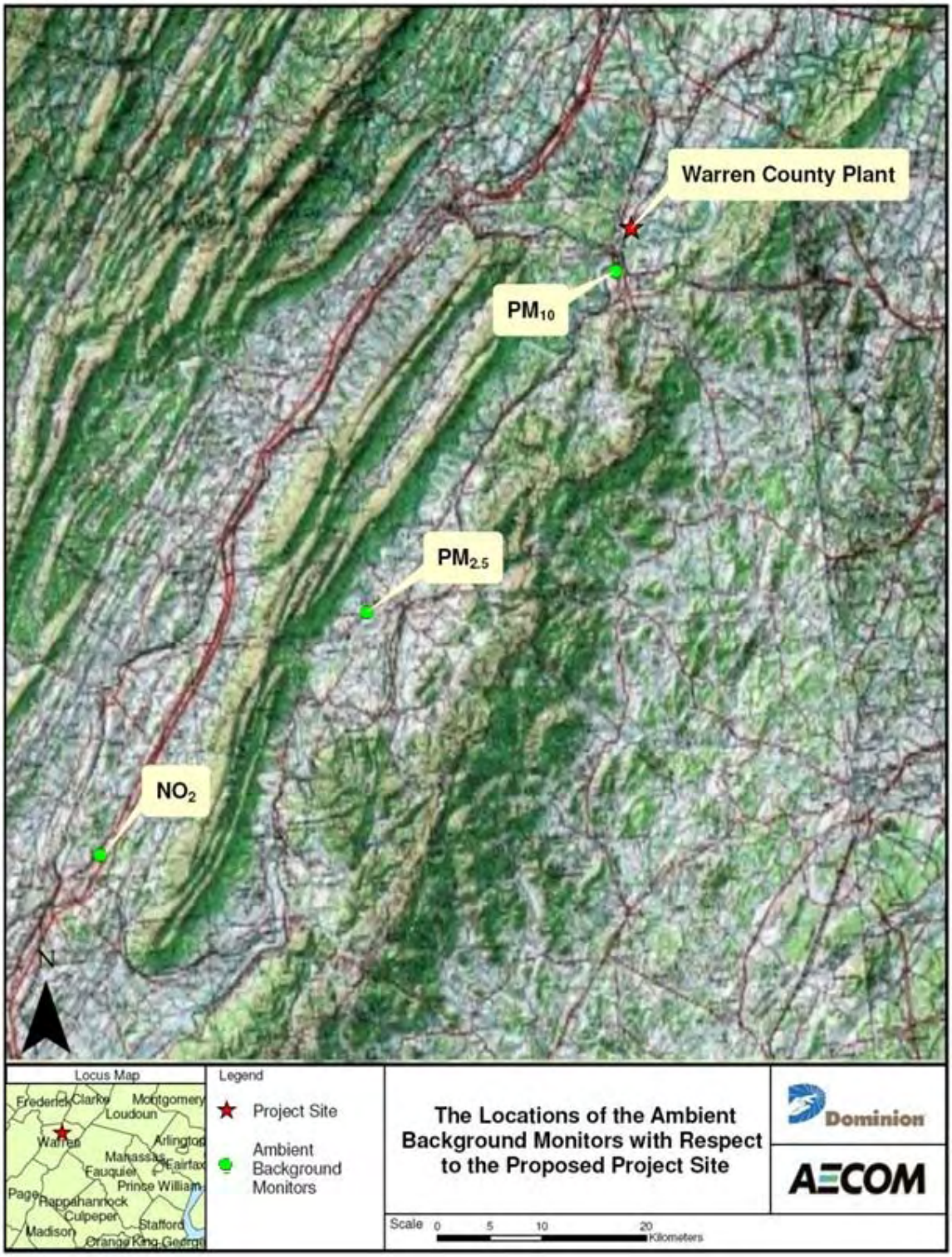
The background air quality data presented in Table 6-15 will be added to modeled concentrations to determine compliance with the applicable NAAQS either in the Class I or Class II areas.

Table 6-15 Proposed Ambient Background Concentrations

Pollutant	Averaging Period	Year	Background Concentrations (ug/m^3)	Monitoring Station
PM_{10}(1)	24-hr(4)	2006	36.00	Front Royal, Warren County
	24-hr(3)	2007	32.00	Front Royal, Warren County
	24-hr(3)	2008	36.00	Front Royal, Warren County
NO_2(2)	1-hr	2007-2009	75.2	Harrisonburg, Rockingham County
$PM_{2.5}$(3)	24-hr	2008	28.00	Luray Caverns Airport, Page County
$PM_{2.5}$(3)	Annual	2008	11.70	Luray Caverns Airport, Page County

(1) Background data taken from the 2006-2008 USEPA AirData database.
(2) Background value supplied by Virginia DEQ
(3) Design value from taken from Virginia Ambient Air Monitor 2008 Report Data
(4) 2nd highest maximum value used

Figure 6-9 Location of the Ambient Background Monitors with respect to the Project Site



7.0 Class II Area Significant Impact Level (SIL) Analysis Results and Cumulative Impact Assessment Methodology and Results

In this section, results of the air quality impact analyses performed for the proposed project are presented. These air quality analyses were conducted using the inputs and methodologies described in Section 6 of this report. Discussions to be found in this section include the projected impacts of the proposed project relating to Significant Impact Levels.

The air quality modeling analysis results are presented in the following discussions and are summarized in a series of tables. In accordance with the VA DEQ requirements, all modeling input and output files are included on a compact disc (DVD) in Appendix F.

7.1 Normal Operation

The first step in an air quality analysis is to determine if the proposed facility will result in significant impacts for any criteria pollutant. Section 6 contains a discussion of the pollutant specific criteria for determination of significant impacts. The Federal SILs are presented in Table 6-1. The SILs define the impact thresholds that establish the complexity of the air quality analysis required to support the permitting of a new or modified facility. A refined modeling analysis, consisting of a cumulative impact study, must be conducted for each pollutant predicted to exceed its respective SIL. If results of the modeling analysis demonstrate that all maximum impacts are less that the SILs, then a cumulative evaluation is not required for criteria pollutants.

Note that the modeling reflects the following operational restrictions/assumptions:

- The annual emission rate for the combined-cycle turbines is based on 8,760 hours per year.
- The inlet turbine chiller will operate up to 8,760 hours per year.
- The auxiliary boiler will operate up to 8,760 hours per year.
- The diesel-fired fire-water pump and diesel-fired emergency generator are expected to operate one (1) hour per week and 52 hours per year under non-emergency conditions (warranty testing).
- The fuel gas heater will operate up to 8,760 hours per year.

As mentioned earlier, the short-term emission rates for the diesel generator and the fire-water pump engine were normalized based on 1 hour per week, but this hour was conservatively modeled such that it can occur any hour of the year. Similarly, the annual emission rates were annualized based on the 52 hours per year for these units.

Tables 7-1 through 7-4 provide detailed summaries of the AERMOD modeling results for the Class II Cartesian grid and fence line receptors. These tables present the maximum ground level concentrations at each of the four operating loads for the Cartesian receptor grid for NO_X annual, PM_{10} annual and PM_{10} 24-hour, and CO 1-hour and 8-hour pollutants. The PM_{10} 24-hour impacts tabulated below are for the

Class II Cartesian grid, fence line receptors and the additional refined receptor grid. The maximum ground level concentrations for PM_{10} 24-hour correspond to the refined receptor grid – refined receptors around the maximum impact and the regular Cartesian grid. Each of the four load groups include the three combined-cycle combustion turbines at the respective load, inlet turbine chillers, auxiliary boiler, diesel-fired fire-water pump, diesel-fired emergency generator and fuel gas heater.

Table 7-1 AERMOD SIL Modeling Results – 100% Load with Duct Firing Scenario

Pollutant	Averaging Period	Maximum Concentration ($\mu g/m^3$)	Worst Case Year	SIL	Significant? (Yes or No)	SIA (km)
NO_X	Annual	0.52	1988	1	No	-
PM_{10}	24-Hour	6.74	1990	5	Yes	9.7
	Annual	0.33	1988	1	No	-
CO	1-Hour	301.79	1992	2000	No	-
	8-Hour	28.67	1988	500	No	-

Table 7-2 AERMOD SIL Modeling Results – 100% Load Scenario

Pollutant	Averaging Period	Maximum Concentration ($\mu g/m^3$)	Worst Case Year	SIL	Significant? (Yes or No)	SIA (km)
NO_X	Annual	0.51	1988	1	No	-
PM_{10}	24-Hour	4.87	1990	5	No	-
	Annual	0.32	1988	1	No	-
CO	1-Hour	301.75	1992	2000	No	-
	8-Hour	28.67	1988	500	No	-

Table 7-3 AERMOD SIL Modeling Results – 75% Load Scenario

Pollutant	Averaging Period	Maximum Concentration ($\mu g/m^3$)	Worst Case Year	SIL	Significant? (Yes or No)	SIA (km)
NO_X	Annual	0.54	1988	1	No	-
PM_{10}	24-Hour	4.22	1990	5	No	-
	Annual	0.37	1988	1	No	-
CO	1-Hour	301.75	1992	2000	No	-
	8-Hour	28.67	1988	500	No	-

Table 7-4 AERMOD SIL Modeling Results – 60% Load Scenario

Pollutant	Averaging Period	Maximum Concentration ($\mu g/m^3$)	Worst Case Year	SIL	Significant? (Yes or No)	SIA (km)
NO_X	Annual	0.60	1988	1	No	-
PM_{10}	24-Hour	4.10	1990	5	No	-
	Annual	0.43	1988	1	No	-
CO	1-Hour	301.75	1992	2000	No	-
	8-Hour	28.67	1988	500	No	-

7.2 Startup/Shutdown Operations

As mentioned earlier in Section 6, a startup/shutdown analysis was completed for all the criteria pollutants subject to PSD review based on the direction received by VA DEQ. Table 7-5 provides summary of the AERMOD modeling results for the Class II Cartesian grid and fence line receptors. The short-term pollutants were modeled for either a cold or a warm startup and the remaining time in the averaging period with the normal operation emissions at 100% with duct firing load. The annual pollutants were modeled based on a combination of annualized startup/shutdown emissions with startup/shutdown stack parameters and the annualized normal operation emissions with their respective stack parameters across all the operating loads.

Table 7-5 AERMOD Modeling Results – Startup/Shutdown Operations

Pollutant	Averaging Period	Maximum Concentration ($\mu g/m^3$)	Worst Case Year	SIL	Significant? (Yes or No)	SIA (km)
NO_X	Annual	0.53	1988	1	No	-
PM_{10}	24-Hour	3.91	1989	5	No	-
	Annual	0.37	1988	1	No	
CO	1-Hour	869.70	1988	2,000	No	-
	8-Hour	139.21	1990	500	No	-

7.3 Summary of Significant Impact Analysis

A comparison of the overall maximum pollutant impacts with the Class II Significant Impact Levels is presented in Table 7-6. For each pollutant and averaging period, the table lists the maximum predicted concentration for all years of meteorological data and worst-case turbine operating loads during the normal operations or startup/shutdown operations.

Table 7-6 Summary of Maximum AERMOD Concentrations to Significant Impact Levels

Pollutant	Averaging Period	Maximum Concentration ($\mu g/m^3$)	Worst Case Year Modeled	SIL ($\mu g/m^3$)	Significant? (Yes or No)	SIA (km)
NO_X	Annual	0.60	1988	1	No	-
PM_{10}	24-hour	6.74	1990	5	Yes	9.7
	Annual	0.43	1988	1	No	-
CO	1-hour	301.79	1992	2000	No	-
	8-hour	28.67	1988	500	No	-

As is depicted in Table 7-6, modeled concentrations for CO 1-hour and 8-hour, PM_{10} annual and NO_X annual are below the corresponding SILs. No further analyses were required for these pollutants at the indicated averaging periods. However, modeled concentrations for PM_{10} 24-hour exceeded the corresponding SIL. Therefore, a cumulative impact assessment for PM_{10} 24-hour was necessary which is presented in the following sections.

The contours showing the maximum impacts across all the operating loads and the worst- case year have been presented in Appendix H for all the criteria pollutants.

7.4 Pre-Construction Monitoring

Table 7-7 presents a comparison of the proposed project's highest predicted impacts with the monitoring exemption concentrations. Since VOC emissions for the proposed project exceed 100 tons per year, ambient air quality data from the nearest monitor, Luray Caverns Airport, has been included in Appendix F for the VA DEQ's approval. Since predicted impacts are below the monitoring exemption concentrations, Dominion hereby requests a waiver from the PSD pre-construction monitoring requirement from VA DEQ's Air Quality Assessment Group (AQAG).

Table 7-7 Comparison of Predicted Impacts with Monitoring Exemption Concentrations

Pollutant	Averaging Period	Maximum Concentration ($\mu g/m^3$)(1)	De Minimis Monitoring Concentration ($\mu g/m^3$) (2)
NO_X	Annual	0.60	14
CO	8-Hour	28.67	575
PM_{10}	24-Hour	6.74	10

(1) Highest impacts from AERMOD Modeling (from Table 7-6)
(2) 9 VAC 5-80-1695 E

7.5 Methodology for the Cumulative Impact Assessment

As demonstrated in Sections 7.1 and 7.2, a cumulative impact assessment is required for the PM_{10} 24-hour as the maximum modeled concentration was found to be above the corresponding SIL. The sections that follow describe the methods that were used to compile the data and perform the multi-source modeling analysis. A complete nearby source emission inventory is provided on the DVD (along with other modeling files) in Appendix F.

7.6 Modeling Approach

The area to be assessed for compliance with the PSD increment and NAAQS was limited to the areas where the Project has a significant air quality impact. Listed below is a general summary of the multi-source modeling that was performed for compliance with the NAAQS and PSD increment consumption. A conservative approach for the PSD increment analysis was followed. All the nearby sources that were modeled as NAAQS sources were considered to be PSD increment-consuming sources. Additional details are provided on these steps in the sections that follow:

Step 1

AECOM developed the initial nearby source inventories with the assistance of the VA DEQ, the West Virginia Department of Environmental Protection (WV DEP), and the Maryland Department of the Environment (MDE) based on a preliminary Significant Impact Area (SIA).

Step 2

AECOM determined the SIA for PM_{10} 24-hour as it exceeded the SIL.

Step 3

AECOM used AERMOD to model the nearby sources along with the proposed project sources.

Step 4

The modeling results were compared to NAAQS and PSD increments to determine compliance. The appropriate background concentrations for the NAAQS compliance demonstration were obtained from the USEPA Airdata database for the most recent years (2006-2008) to account for distant or minor sources that were not explicitly modeled.

7.7 Determination of Significant Impact Area

The significance modeling that was conducted for the proposed project sources in AERMOD was used to determine the SIA for each pollutant exceeding its respective SIL. The screening radius was determined by adding 50 km to the SIA. The screening radius is the basis for obtaining a nearby source inventory for the NAAQS and PSD Increment Compliance analysis. For this proposed project, the domain for evaluating the nearby sources extended into West Virginia and Maryland. The sources listed in the emission inventories were evaluated in the screening analysis if they were inside the screening radius.

The SIA radius and the corresponding screening radius for PM_{10} 24-hour averaging period is provided below.

PM_{10} 24 Hour:	9.7 km	59.7 km

7.8 Nearby Emission Source Inventories

This section describes the steps that were taken in compiling the data in the nearby emission source inventories for appropriate use in the multi-source modeling analyses. For the initial inventory, a summary of sources which emit pollutants above the SIL was developed based on a preliminary SIA. These sources were obtained from the source emission inventory provided by VA DEQ, WV DEP, and MDE, respectively. A list of the nearby emission sources that were included in the multi-source modeling is provided in Appendix G. The complete nearby emission source inventories are provided on the DVD (along with the other modeling files) in Appendix F. A few subsections follow below to describe unique aspects of each state's inventory.

7.8.1 Virginia Inventory

The emission inventory for the area covered by the screening radius in Virginia was provided by VA DEQ in spreadsheet format. Only the NAAQS source inventory was provided for PM_{10}. All the NAAQS sources which were within the screening radius (50 km plus the SIA) were assumed to be PSD increment-consuming sources. Missing data points were filled using the 2005 NEI database.

The missing base elevation of the sources/facilities included in the NAAQS and PSD Increment Compliance Analyses were filled with the base elevations of the sources with the same coordinate location.

7.8.2 West Virginia Inventory

The domain for evaluating nearby emission sources extended into West Virginia and therefore an emission inventory was requested from WV DEP. Only the NAAQS source inventory was provided for PM_{10}. All the NAAQS sources which were within the screening radius (50 km plus the SIA) were assumed to be PSD increment-consuming sources. The inventory had some missing stack parameters that were filled with appropriate stack parameters to represent the worst-case modeling scenario.

The missing base elevations of the sources/facilities included in the NAAQS and PSD Increment Compliance Analyses were obtained from the Topozone website (www.topozone.com). An averaged coordinate location was used to get a base elevation for all the sources of that facility.

7.8.3 Maryland Inventory

The domain for evaluating nearby emission sources extended into Maryland and therefore an emission inventory was requested from MDE. Only the NAAQS source inventory was provided for PM_{10}. All the NAAQS sources that were within the screening radius (50 km plus the SIA) were assumed to be PSD consuming sources. The inventory had some missing stack parameters that were filled with appropriate stack parameters to represent the worst-case modeling scenario.

The missing base elevations of the sources/facilities included in the NAAQS and PSD Increment Compliance Analyses were obtained from the Topozone website (www.topozone.com). An averaged coordinate location was used to get a base elevation for all the sources of that facility.

7.8.4 Adjustments to the Inventory

Since the initial emission inventories were developed from a larger preliminary SIA and corresponding screening radius, there were some sources in the inventories that were now outside the actual screening radius. The first screening method was to eliminate the sources in the inventories that were outside the actual pollutant specific screening radius. The calculations for this screening method, which is a part of the complete emission inventory, are provided on the DVD in Appendix F.

Any missing stack parameters in the VA DEQ's inventory were filled with the 2005 NEI database. Any missing stack parameters in the WV DEP's and MDE's inventory were filled with appropriate stack parameters to represent a worst-case modeling scenario. Values of 10 ft for the stack height, 68°F for the stack exit temperature, 0.0003 fps for the stack exit velocity and 0.003 ft for the stack diameter were used to fill the data gaps in the WV and MD inventories. However based on some limitations in the number of decimal places that can be used in the AERMOD interface, stack exit velocity was made consistent with that of the horizontal stacks at 0.001 m/s (0.003 fps).

7.9 Application of the Multi-Source Modeling Analysis

As previously mentioned, the AERMOD model was used in the multi-source modeling analyses. After a thorough evaluation of the nearby sources for the multi-source modeling, the application of the model was determined. The methodology is discussed below.

For NAAQS compliance, AECOM used AERMOD to model the nearby NAAQS emission sources along with the proposed project's sources in simple and complex terrain. The objective for using this model is to capture cumulative impacts within the SIA.

For the proposed project, the same stack parameters and emission rates (see Section 6 for details) as used for the SIL modeling was used for the multi-source modeling analyses. The model receptor grid consisted of receptors that exceeded SILs for the PM_{10} 24-hour multi-source application. The cumulative receptor grid consisted of the receptors that exceeded the PM_{10} 24-hr SIL for each load and each year. Any duplicate receptors were deleted from the combined receptor grid. The same set of meteorological data from the SIL Analysis was used for this analysis.

The high second-high (short-term pollutants) impacts were retrieved, and added to the corresponding monitored background concentration averaged over 2006-2008 provided in Table 6-15. These final values were then compared to the NAAQS to determine compliance. Figure 6-9 shows the location of the ambient background monitors for the criteria pollutants considered in the analysis. Compliance with the 24-hr PM_{10} NAAQS is typically based upon the H6H computed over the *entire* five years of meteorological data. However, this analysis used the H2H PM_{10} concentration to demonstrate NAAQS compliance. The H2H PM_{10} concentrations are a conservative indicator (overestimate) of the H6H values.

The same modeling procedures and applications described above were applied to the PSD Increment analysis, with the exception that monitored background concentrations were not added to the modeled impacts for the PSD Increment compliance evaluation.

7.10 Results of the Multi-Source Modeling Analysis

The results of the multi-source modeling analysis are presented in the following sub-sections below.

7.10.1 Summary of NAAQS Analysis

A complete summary of the NAAQS analysis is presented in Table 7-8. "High 2nd High (H2H) Model Concentration" refers to the combined impacts from the proposed project sources and the NAAQS background sources. The model concentrations were determined by finding the H2H (short-term) impacts from the AERMOD model. The appropriate monitored background concentration was added to the high 2nd high model concentration to obtain the final concentration, which is listed in the "Total Concentration" column, for comparison to the NAAQS. The table below presents the high 2nd high model concentration over the four operating loads and five years of meteorological data.

As shown in Table 7-8, the predicted impacts for PM_{10} 24-hour in the NAAQS cumulative impact analysis will be less than the NAAQS. The results of the NAAQS modeling analysis show that the project will not cause or contribute to a NAAQS violation. Hence, the proposed project is deemed to be in compliance with the applicable NAAQS standards.

Table 7-8 Summary of NAAQS Analysis

Pollutant	Averaging Period	High 2nd High Model Concentration ($\mu g/m^3$)	Monitored Background Concentration ($\mu g/m^3$) (1)	Total Concentration ($\mu g/m^3$)	NAAQS ($\mu g/m^3$)	Complies (Y/N)?
PM_{10}	24-hour	4.98 (4.92)(2)	34.70	39.68	150	Y

(1) Average monitored background concentration over 2006-2008.
(2) Dominion project contribution shown in parentheses.

7.10.2 Compliance with PSD Increment

A complete summary of the PSD Increment Analysis is presented in Table 7-9. "High 2nd High Model Concentration" refers to the combined impacts from the proposed project sources and other nearby modeled PSD Increment-consuming sources. The model concentrations were determined by finding the H2H (short-term) impacts from the AERMOD model. The high 2nd high concentrations were compared with the Class II Increment values.

As shown in Table 7-9, the predicted impacts for all criteria pollutants in the Increment cumulative impact analysis will be less than the corresponding standard values. The results of the increment modeling analysis show that the project will not exceed the allowable increments. Hence, the proposed project will not cause or contribute to a Class II area PSD increment violation for PM_{10}.

Table 7-9 Summary of PSD Increment Analysis

Pollutant	Averaging Period	High 2nd High Model Concentration ($\mu g/m^3$)	PSD Increments ($\mu g/m^3$)	Complies (Y/N)?
PM_{10}	24-hour	4.98 (4.92)(1)	30	Y
(1) Dominion project source contribution shown in parentheses.				

8.0 Class I Area Modeling Analysis

8.1 Modeling Procedures

Figure 8-1 shows the location of the Project relative to PSD Class I areas. It is noteworthy that while the closest Class I area, Shenandoah National Park, has its closest point within 10 km of the Project site, the next closest Class I area, Dolly Sods Wilderness Area, is about 100 km away. Dolly Sods is also in a location associated with a very low wind direction frequency from the proposed project.

In accordance with the draft FLAG 2009 guidance that is recommended by the Federal Land Managers, we excluded from modeling consideration Class I areas that are beyond the FLAG-specified screening distance from the Project site. The screening distance was determined by adding the permitted short-term emissions from proposed routine (non-emergency) point sources for SO_2 + NO_x + PM_{10} + H_2SO_4. The sum of these emissions for the scenario with the highest emissions is not expected to exceed 600 tons per year, based upon information provided in Section 3. With a FLAG-prescribed screening distance of 600/10 = 60 km, this confirms that only impacts within the Shenandoah National Park need to be considered for Air Quality Related Values (AQRVs). Therefore, we conducted all Class I modeling with a focus upon the portion of Shenandoah National Park within 50 km of the Project site using AERMOD. We used the same modeling platform and approach as that used for the PSD Class II modeling (described in Section 6). Treatment of the emission sources was the same for the Class II and Class I modeling.

Figure 8-2 shows the receptor coverage of this portion of the park. The grid consists of receptors spaced at 100 m out to 10 km from the Project site, 500 m between 10 and 30 km from the Project site, and 1000 m spacing between 30 and 50 km from the Project site.

Figure 8-1 Location of the Proposed Project Relative to Nearby Class I Areas

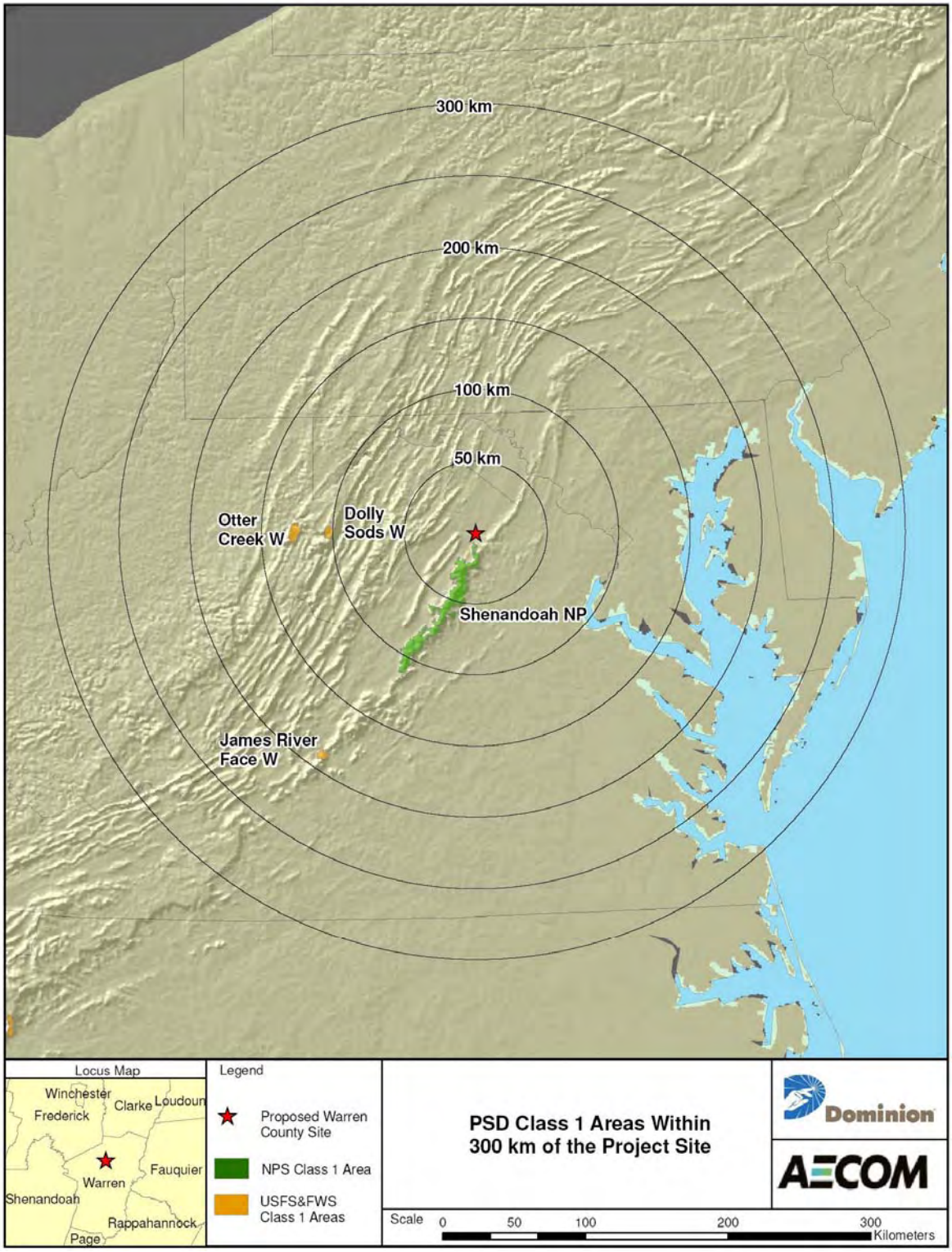
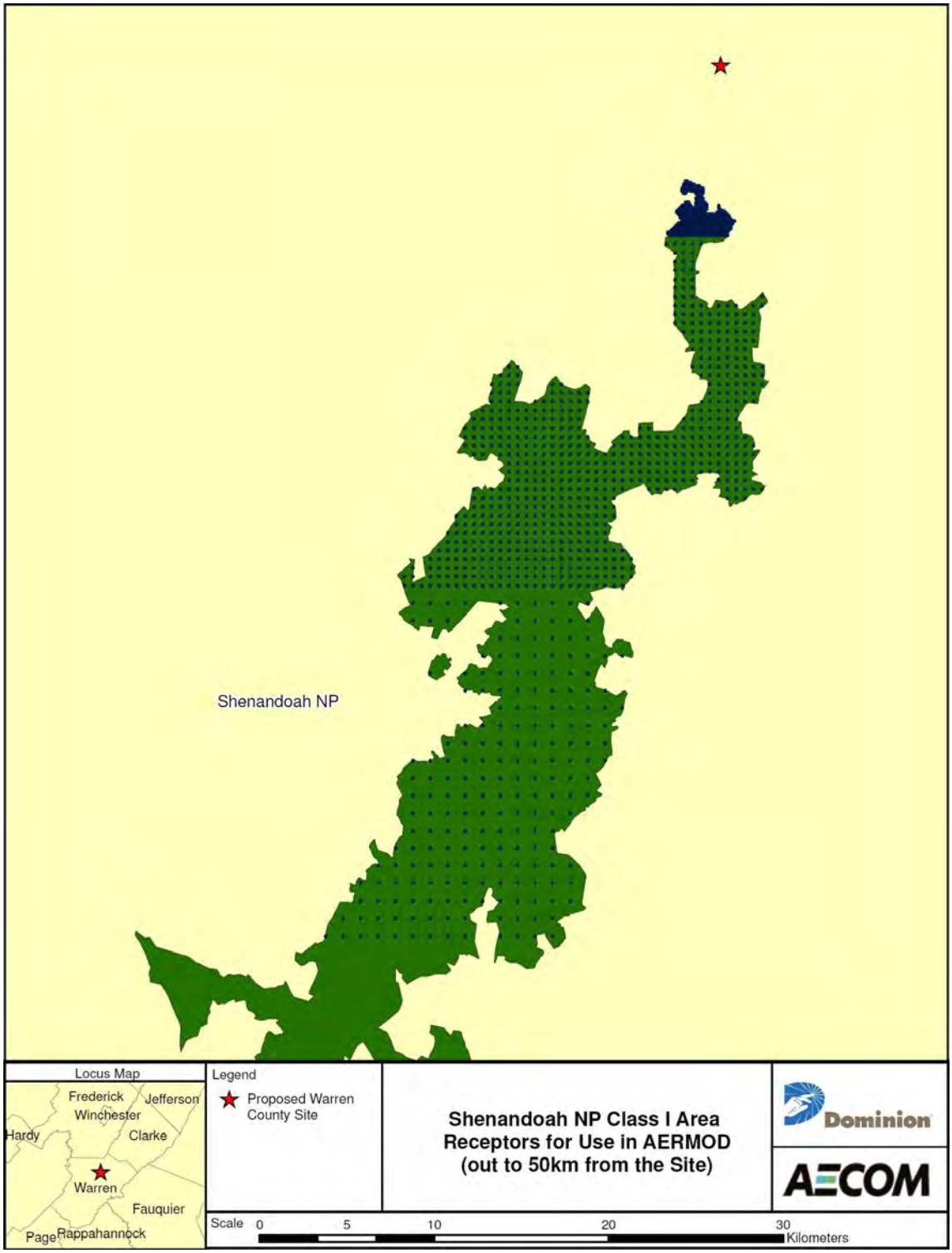


Figure 8-2 Receptor Coverage in Shenandoah National Park



For the Class I modeling that was conducted in areas within 50 km of the Project site, the considerations for the modeling requirements and modeling selection were the same for both Class I and Class II areas. This approach is described in Section 6.

For estimating deposition of acidic species associated with emissions of NO_X and SO_2, we followed a tiered screening approach. For sulfur deposition associated with SO_2 emissions, the Tier 1 Screening method in IWAQM Phase 1 multiplies the modeled annual average SO_2 concentration by a deposition velocity of 0.5 cm/sec. For nitrogen deposition associated with NO_X emissions, the Tier 1 Screening method in IWAQM Phase 1 assumes that all NO_X emitted is readily transformed to nitric acid as it enters the atmosphere. The annual nitrogen deposition is then estimated by multiplying the modeled annual average concentration by a deposition velocity of 5 cm/sec. The deposition velocity for nitric acid is more than an order of magnitude greater than that for either NO or NO_2. This simplified screening approach is likely to be overly conservative in this case because only a small fraction of NO_X emissions would be expected to be transformed to nitric acid over nearby Shenandoah National Park.

Therefore, we found it useful for nitrogen deposition to conduct a Tier 2 screening assessment that incorporated a conservative, but more realistic, estimate of nitric acid formation and deposition. This approach still used the conservatively high deposition velocity of 5 cm/sec. However, the average rate of conversion of NO_X to HNO_3 was computed by applying the following equation for nitrate transformation rate (k, % per hour), which is used in CALPUFF when the default MESOPUFF II chemistry module is selected:

For daytime conditions, the transformation rate (k_3) in %/hr is:

$$k_3 = 1261 \left[O_3\right]^{1.45} S^{-1.34} \left[NO_x\right]^{-0.12}$$

,

where:

S is the stability category (1=A, 6=F),

$[O_3]$ is the ambient ozone concentration (ppm), and

$[NO_X]$ is the average modeled concentration (ppm) within the plume (modeled with a simple Gaussian equation).

The following hourly data was used to implement the refined method for daytime hours:

- hourly ozone data from the Shenandoah Big Meadows CASTNET site (concurrent with the AERMOD meteorological data)
- stability class computed from the AERMET-provided friction velocity and Monin-Obukhov length using the Golder (1972) algorithm to calculate the stability class (code from the AERMOD subroutine “LTOPG”)

For nighttime conditions, the transformation rate (k_4) is 2%/hr.

The nitrate species that are formed are typically comprised of ammonium nitrate and nitric acid, with the ratio depending on a variety of factors, including the availability of ammonia and ambient temperature. Ammonium nitrate is a fine particulate that has a much lower deposition velocity than nitric acid, which is highly reactive. In cold and humid conditions, ammonium nitrate is more likely to form. Due to the NNE trajectory of winds required to transport the plume from the Project site to Shenandoah, it is likely that colder than average temperatures would prevail for transport, thus favoring the formation of ammonium nitrate with the much lower deposition velocity. For this Tier 2 screening assessment, it was conservatively assumed that all nitrate formed from NO_X emissions is in the form of nitric acid, acknowledging that a the actual deposition velocity could be substantially lower.
.

The deposition of nitrogen due to deposition of HNO_3 was then conservatively computed according to the following equation for each hour of the the worst-case year identified by Tier 1 for the Shenandoah receptor location for which the Tier 1 screening deposition analysis indicated the maximum deposition would occur. An hourly computation for the refined approach was followed for the worst-case receptor for annual deposition. The hourly deposition values were then summed to estimate the annual deposition.

Nitrogen deposition (kg/ha/hr) =

V_d * [NO_X] * MWR *(1-exp(-k/100)*X/u)) * (3600 sec/hr) * (10^4 m^2/ha) * (10^{-9} kg/µg)

Where:

X= distance (km) to the Class I area receptor,

k = NO_3 conversion rate for daytime and nighttime conditions (%/hr)

MWR = ratio of molecular weight of atomic nitrogen to nitrogen dioxide = 0.3043

u= wind speed (km/hr),

[NO_X] = modeled ground-level concentrations at the receptor of interest (µg/m^3), and

V_d = the IWAQM nitric acid deposition velocity = 0.05 m/sec.

The conservatively modeled sulfur and nitrogen deposition values are reported later in this report and compared to the conservatively low screening Deposition Analysis Thresholds (NPS, 2002) for the Eastern United States of 0.010 kg/ha/yr.

For plume visibility impacts inside Shenandoah National Park within 50 km, the PLUVUE II model was used, consistent with past permitting on this project. The procedures for this analysis have been established and agreed to by the National Park Service for the previous permitting of the Warren County project (previously called “CPV Warren”) at the same site (see TRC Class I modeling report, 2003). The results of the PLUVUE II modeling analysis are described below in this report.

8.2 Class I Area Results for Project-Only Impacts

Due to the proximity of the project site to the Shenandoah National Park (within 10 km), there is an additional trigger for PSD review, if “any emissions rate or any net emissions increase associated with

a major stationary source or major modification, which could construct within 10 km of a Class I area, and have an impact on such area equal to or greater than 1 $\mu g/m^3$ (24-hour average)". This trigger could potentially affect SO_2 and Pb. However, the modeling results for SO_2 indicate that the highest 24-hour predicted concentration at any receptor within the park is only about 0.2 $\mu g/m^3$. Therefore, the project does not trigger PSD review for SO_2. Since the SO_2 modeling results are less than 1 $\mu g/m^3$ in the Class I area, it can be inferred from the SO_2 modeling results that the Pb modeling (and modeling for other pollutants with emissions less than SO_2) would result in impacts less than 1 $\mu g/m^3$ in Shenandoah National Park as well because the SO_2 emissions are higher than those for Pb (and other applicable pollutants) for all modeled sources. Project Pb (and other pollutant) emissions are presented in Appendix B of the Air Permit Application

The first step in the PSD Class I air quality analysis involved a comparison of the modeled impacts of PM_{10} and NO_2 to the proposed SILs, as listed in Table 8-1. Modeling of CO was not conducted because the Class II impacts reported in Section 7 show results well below the Class II SIL, and there is no separate Class I SIL for CO. The emissions used in the Class I modeling are the same as those used for the Class II modeling.

Tables 8-2 through 8-5 provide detailed summaries of the AERMOD modeling results for the Class I receptor grid. These tables present the maximum ground level concentrations at each of the four operating loads. Each of the four load groups include emissions from the three combined-cycle combustion turbines at the respective load, inlet turbine chiller, auxiliary boiler, diesel-fired fire-water pump, diesel-fired emergency generator and fuel gas heater. The results show that the project has significant impacts in the Shenandoah National Park for NO_2 and PM_{10}. A cumulative modeling analysis was conducted for these pollutants for compliance with the NAAQS (see Section 8.3) and PSD increments (see Section 8.4).

Table 8-1 Proposed Significant Impact Levels for PSD Class I Areas

Pollutant	Averaging Time	
	Annual ($\mu g/m^3$)	24-hour ($\mu g/m^3$)
NO_2	0.1	-
PM_{10}	0.2	0.3
Source: Federal Register, 23 July 1996.		

Table 8-2 AERMOD SIL Modeling Results – 100% Load with Duct Firing Scenario

Pollutant	Averaging Period	Maximum Concentration ($\mu g/m^3$)	Worst Case Year	SIL	Significant? (Yes or No)
NO_2	Annual	0.22	1988	0.1	Yes
PM_{10}	24-Hour	5.55	1989	0.3	Yes
	Annual	0.18	1988	0.2	No

Table 8-3 AERMOD SIL Modeling Results – 100% Load Scenario

Pollutant	Averaging Period	Maximum Concentration ($\mu g/m^3$)	Worst Case Year	SIL	Significant? (Yes or No)
NO_2	Annual	0.22	1988	0.1	Yes
PM_{10}	24-Hour	3.99	1989	0.3	Yes
	Annual	0.18	1988	0.2	No

Table 8-4 AERMOD SIL Modeling Results – 75% Load Scenario

Pollutant	Averaging Period	Maximum Concentration ($\mu g/m^3$)	Worst Case Year	SIL	Significant? (Yes or No)
NO_2	Annual	0.24	1988	0.1	Yes
PM_{10}	24-Hour	3.41	1989	0.3	Yes
	Annual	0.19	1988	0.2	No

Table 8-5 AERMOD SIL Modeling Results – 60% Load Scenario

Pollutant	Averaging Period	Maximum Concentration ($\mu g/m^3$)	Worst Case Year	SIL	Significant? (Yes or No)
NO_2	Annual	0.27	1988	0.1	Yes
PM_{10}	24-Hour	3.09	1989	0.3	Yes
	Annual	0.21	1988	0.2	Yes

8.3 Cumulative Analysis for NAAQS Compliance in Shenandoah National Park

For the PM_{10} and NO_2 NAAQS cumulative modeling compliance analysis, AECOM contacted the VA DEQ and the WV DEP for a list of nearby sources within 50 km of the Shenandoah National Park, within the area shown in Figure 8-3. Only nearby emissions sources within 50-km of Shenandoah were considered for inclusion into the cumulative modeling analysis.

The results of the cumulative NAAQS compliance modeling analysis for PM_{10} and NO_2 are presented in Table 8-6. The results indicate that the total predicted impacts are well below the daily PM_{10} NAAQS (note that EPA has withdrawn the annual PM_{10} NAAQS) as well as the annual NO_2 NAAQS.

Table 8-6 Cumulative NAAQS Compliance Modeling Results for Shenandoah National Park

Pollutant	Averaging Period	Model Concentration ($\mu g/m^3$)	Monitored Background Concentration ($\mu g/m^3$) (1)	Total Concentration ($\mu g/m^3$)	NAAQS ($\mu g/m^3$)	Complies (Y/N)?
NO_2	Annual (Highest)	0.45 (0.27)(2)	12.54	12.99	100	Y
PM_{10}	24-hour (High 2nd High)	5.15 (5.10)(2)	34.67	39.82	150	Y

(1) Average monitored background concentration over 2006-2008.
(2) Dominion project contribution shown in parentheses.

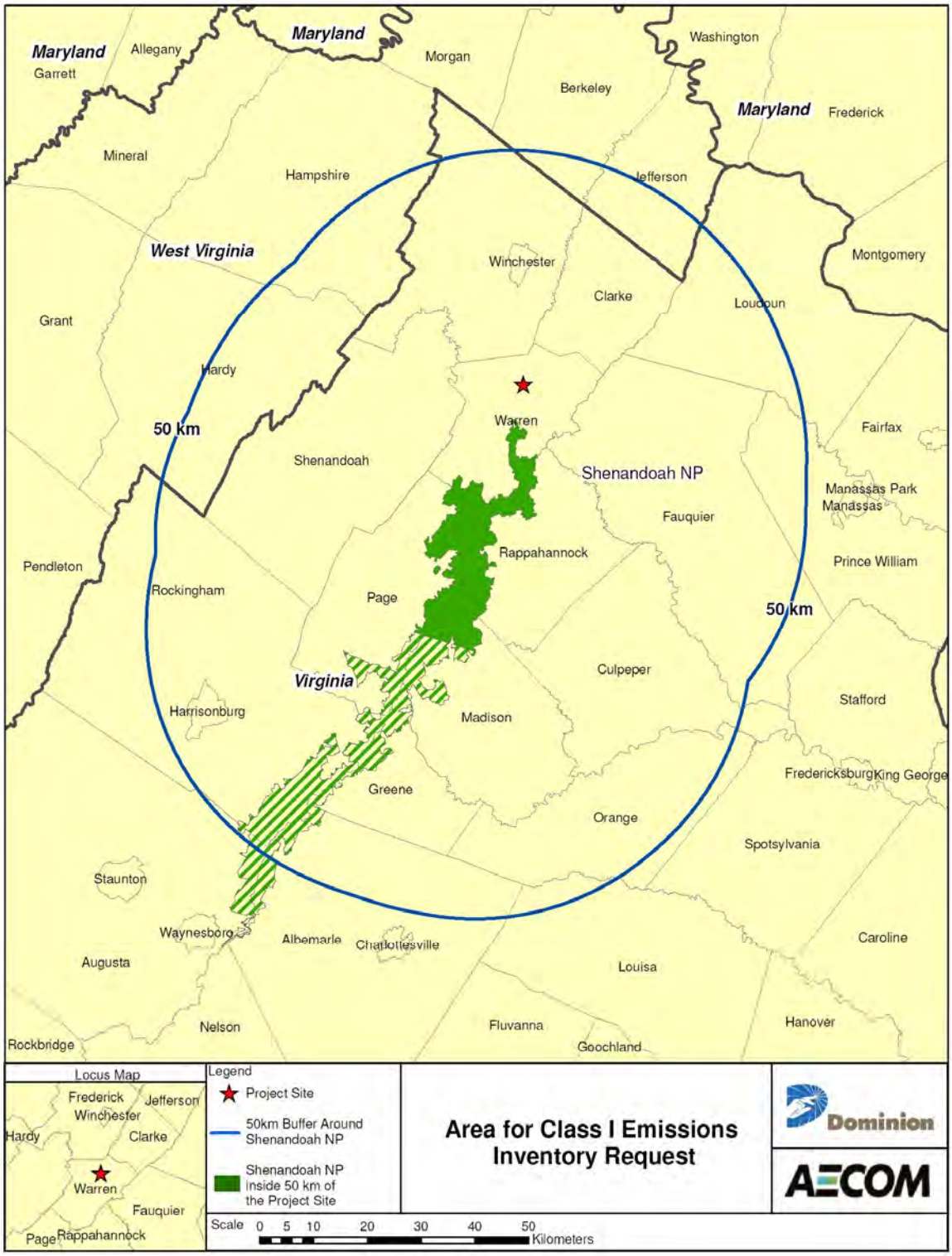
8.4 Cumulative Analysis for PSD Increment Consumption in Shenandoah National Park

The source inventory received from Virginia and West Virginia did not specify which sources are PSD increment-consuming. For a Tier 1 approach, we conservatively assumed that all reported sources consume increment. The results of the PSD increment modeling analysis for PM_{10} and NO_2 are presented in Table 8-7. The results of the PSD increment modeling analysis with this conservative assumption show that the project will not cause or contribute to a PSD increment violation for PM_{10} and NO_2 in the Shenandoah National Park.

Table 8-7 Cumulative PSD Increment Modeling Results for Shenandoah National Park

Pollutant	Averaging Period	Model Concentration ($\mu g/m^3$)	PSD Increments ($\mu g/m^3$)	Complies (Y/N)?
NO_2	Annual (Highest)	0.45 (0.27)(1)	2.5	Y
PM_{10}	24-hour (High 2nd High)	5.15 (5.10)(1)	8	Y
PM_{10}	Annual (Highest)	0.27 (0.21)(1)	4	Y
(1) Dominion project contribution shown in parentheses.				

Figure 8-3 Area for Nearby Source Emissions Modeling for Shenandoah National Park



8.5 Plume Visibility Analysis for Shenandoah National Park

8.5.1 Modeling Procedures

For plume visibility impacts inside Shenandoah National Park within 50 km, the PLUVUE II model was used, consistent with past permitting on this project. The procedures for this analysis have been established and agreed to by the National Park Service for the previous permitting of the CPV project at the same site (see TRC Class I modeling report, 2003).

Following these procedures, the modeling approach consisted of the elements described below.

- Five years of meteorological data (1988-1992) from Dulles airport were used for the analysis, consistent with the other portions of the modeling analysis.
- The 2003 TRC report refers to preliminary seasonal analyses that were conducted to identify a subset of conditions and hours for the PLUVUE II analysis. Details provided in Appendix E of that document describe specific wind directions of interest and consideration of views within the Park itself. This analysis reviewed the PLUVUE results from "typical average" conditions within possible meteorological combinations in order to eliminate most cases for which the plume contrast (|C|) and plume perceptibility (ΔE) results would be less than 85% of the Class I Levels of Concern for PLUVUE II (an absolute value of at least 0.017 for |C| and 0.85 for ΔE). This analysis was repeated for this project due to the higher emissions relative to past permitting for CPV. Groups of hours for which the seasonal PLUVUE II results for "typical average" conditions exceeded these reduced thresholds were modeled individually for each applicable hour of meteorological conditions.
- Specific viewpoints discussed below have been selected for the plume visibility analysis. For each of these viewpoints, the meteorological database was screened for the frequency of the occurrence of appropriate conditions during daylight hours and cases for which the plume was transported close to the observer (within 10 degrees). The final database included only hours with non-overcast conditions because the PLUVUE II model assumes clear skies.
- Emissions rates for SO_2, NO_x, and PM_{10} were consistent with those modeled for criteria pollutant concentrations. Although PLUVUE II double-counts the sulfur atoms in SO_2 and sulfate emissions, the small level of emissions in this case do not warrant an adjustment to PLUVUE II for this input.
- The PM_{10} emission rate includes both filterable and condensable components, including sulfates.

For the previous permitting, the National Park Service and VA DEQ agreed upon five viewpoints to be analyzed for plume visibility effects (see Figure 5-1, copied from the 2003 TRC report referenced above). Three of the selected locations are overlooks situated along Skyline Drive. These areas are directly accessible by automobile, have clear views of terrain, and are relatively unobstructed. Two other viewpoints were added by NPS staff. The viewpoints that were analyzed are described below, and are displayed collectively in Figure 8-4 and individually with lines of sight in Figures 8-5 through 8-9 (copied from the 2003 TRC report).

- Shenandoah Valley Overlook: located about 9 km from the proposed project site, it offers views to the north toward Front Royal.

- Dickey Ridge: located about 11 km from the proposed project site, it offers views to the northeast within the Park, and views to the southeast and southwest toward terrain within the Park.
- Signal Knob Overlook: located about 12.5 km from the proposed project site, it offers fairly long views to the south, southwest, and southeast within Park boundaries. In addition, there is a view toward the west to areas beyond Park boundaries.
- Compton Gap Road: selected as a supplemental viewpoint by the NPS due to its location at the highest point along Compton Gap Road, about 14.6 km from the project site. It offers long views of Park terrain toward the southwest, and shorter views toward the west and northwest.
- Lands Run Road Gate: selected as a supplemental viewpoint by the NPS for its location where Lands Run Road crosses the western boundary of the Park. It is approximately 16.5 km from the proposed project site and it offers long views to the south and southwest, although viewing distances to the east are limited by elevated terrain.

In concurrence with the previously approved methodology, any wind direction that causes the plume centerline to pass within 10 degrees of a viewpoint is excluded from the assessment, because PLUVUE II is known to over-predict in these cases. This excludes the following viewpoint wind direction combinations: for Shenandoah Valley Overlook, Dickey Ridge and Signal Knob Overlook: 10°, 20°; for Compton Gap: 0° and for Lands Run Road Gate: 0° and 10°.

PLUVUE II was run for each hour identified from the 5-year meteorological period for meteorological conditions associated with the Class I Levels of Concern (an absolute value of at least 0.02 for |C| and 1.0 for ΔE). The results of the PLUVUE II analyses were summarized for each viewpoint, and the probability of potential future occurrences during peak project emission periods were calculated by reviewing the frequency of hours determined to be above perceptible visibility thresholds, especially during periods of peak park visitation. Note that the threshold values specified above are considerably more stringent than the values of 0.05 for |C| and 2.0 for ΔE used for the Level 1 and 2 plume visibility modeling.

As a refinement to the assessment using these stringent plume perceptibility thresholds, a supplemental analysis has been conducted to account for effects on plume perceptibility due to the apparent plume width. As noted by Richards et al. (2007),

> "In the real world, plumes are viewed against a background of sky or terrain that does not have a uniform luminance and color, even when there are no clouds. For faint plumes, the effect of a plume is to introduce a small distortion in the luminance and color profile of the background. As the angle subtended by a plume increases (i.e., the plume fills a larger portion of the observers total field of view), the plume is spread over a larger change in the luminance and color of the background sky. For a given value of the plume contrast or color difference, the changes in luminance and color attributable to the plume become a smaller fraction of the naturally occurring variations in the luminance and color of the background sky. Thus, it is reasonable to believe that the adjustment needed to convert laboratory contrast thresholds into thresholds appropriate for the real world increases as the plume subtended angle increases."

The procedures for implementing an adjustment to |C| and ΔE are described by Richards et al. (2007) as well as Zell et al. (2007). This involves computation of the plume angle subtended for each line of

sight and simulated PLUVUE hour, computing appropriate threshold values for |C| and ΔE and then comparing the modeled plume parameter to this threshold.

Perception research by Howell and Hess (1978) showed that the human eye is most sensitive to contrast between a plume and the background for plumes whose apparent width (angle subtended by the plume relative to the observer) ranges from 0.2 to 1.0 degree. The contrast which is required to be perceived by the human eye for wider plumes increases rapidly for larger subtended angles. Similarly, Richards, et al. (2007) have demonstrated that the threshold at which the human eye can detect color difference (ΔE) also increases rapidly as a function of the plume subtended angle, for angles larger than about one degree.

The Levels of Concern for contrast and color difference established in the Federal Land Managers' Air Quality Related Values Workgroup (FLAG) document are near the minima of the perception curves, which occur at small subtended angles where the human eye is most sensitive to contrast and color difference. Modeling experience has shown that the highest contrast and color differences calculated by PLUVUE II occur when the plume centerline passes relatively close to an observer in the Class I area. A plume emitted from a source tens of kilometers away can be hundreds of meters wide at the observer's line of sight, and therefore can subtend an angle much larger than 1 degree. A wide plume may not actually be visible to the observer, even if its contrast or color difference exceeds the low FLAG thresholds which apply to narrow plumes.

The first technical paper provided in Appendix I describes a permitting application, but does not specifically mention the project. However, AECOM discussions with Mr. Pete Catizone of TRC indicate that this procedure was approved for the proposed South Heart Coal project in western North Dakota (the affected Class I area was the Theodore Roosevelt National Park). Pete Catizone and Steve Weber (of the North Dakota Department of Health) recall that the National Park Service approved this modeling approach for the South Heart Coal project. The permit application was subsequently withdrawn.

The second technical paper in Appendix I describes the PLUVUE modeling for the Healy project in Alaska, and refers on page 6 to adjustments of the perception threshold that is dependent upon the plume width.

8.5.2 Plume Visibility Findings

The seasonal plume visibility analysis indicated a number of meteorological conditions for each viewpoint that exceeded the specified thresholds for |C| and ΔE. These meteorological conditions were then used to identify individual hours to be evaluated over the 5-year period in a refined PLUVUE II assessment. This refined assessment estimated the number of hours that the visible plume parameter thresholds could be exceeded. Supplemental information regarding the intensity, geographic extent, duration, frequency and timing of these cases is provided in Appendix F.

Table 8-8 provides the number of excursions, defined as hours when the conservative FLAG visible plume thresholds (0.02 for |C| and 1.0 for ΔE) could be exceeded. The table also provides the associated percentage of the daytime excursions (based on average 12 hours of daytime per day) over the 5-year period. Signal Knob Overlook has the greatest number of excursion hours and Shenandoah Valley Overlook has the fewest hours. At no viewpoint would excursion hours occur more than about 0.5% of the daytime. Following the established protocol, wind directions that cause the plume to nearly pass over (within 10 degrees) a viewpoint were excluded in Table 8-8, because PLUVUE does not adequately simulate this geometry. Table 8-9 provides an indication of the plume

visibility parameters (|C| and ΔE for sky or terrain) that trigger the threshold excursions. |C| and ΔE for terrain background, as opposed to sky, account for the vast majority of the excursions. This indicates that an elevated plume viewed against the background sky would seldom be visible. Because the model simulates terrain with uniform reflectivity (grey, white or black) the degree to which a plume could be visible against actual terrain of various colors is likely to be exaggerated (Henry, 2002).

Table 8-10 provides the results of a refined analysis of the number of excursion hours based on more realistic thresholds for |C| and ΔE, which account for the apparent plume width, as discussed above. The analysis indicates that a plume is likely to be perceptible less than 0.15% of the time at Signal Knob overlook and at a much smaller percentage of the time at other viewpoints. Thus, both the plume visibility assessment using the conservative FLAG perceptibility thresholds and the refined thresholds indicate that the modeled frequency of visible plumes associated with the project will be well less than one percent, the Level 2 significance threshold established in Workbook for Plume Visual Impact Screening and Analysis (U.S. EPA, 1992).

Figure 8-4 Scenic Overlooks Analyzed in PLUVUE II Plume Visibility Analysis

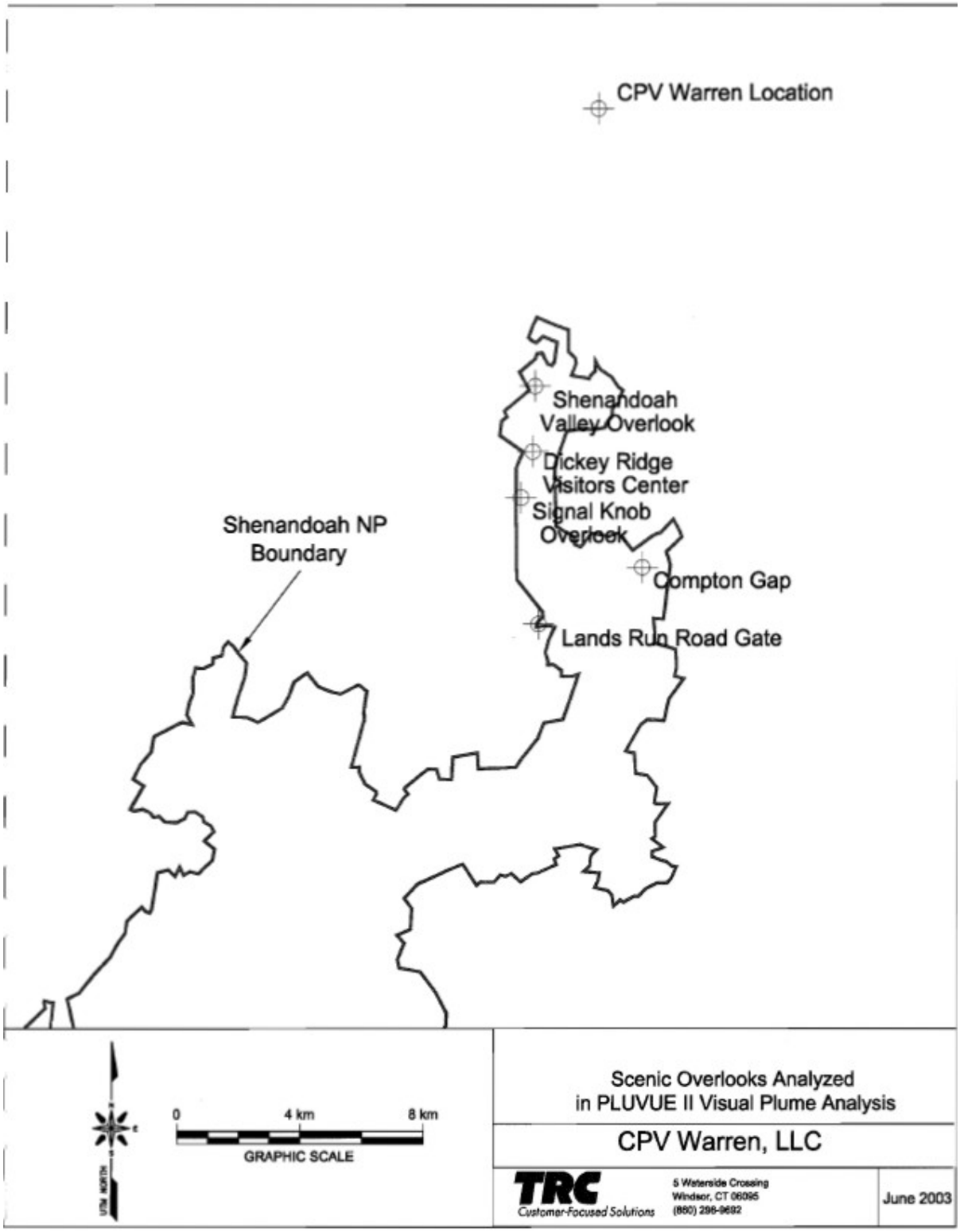


Figure 8-5 Lines of Sight for Shenandoah Valley Overlook

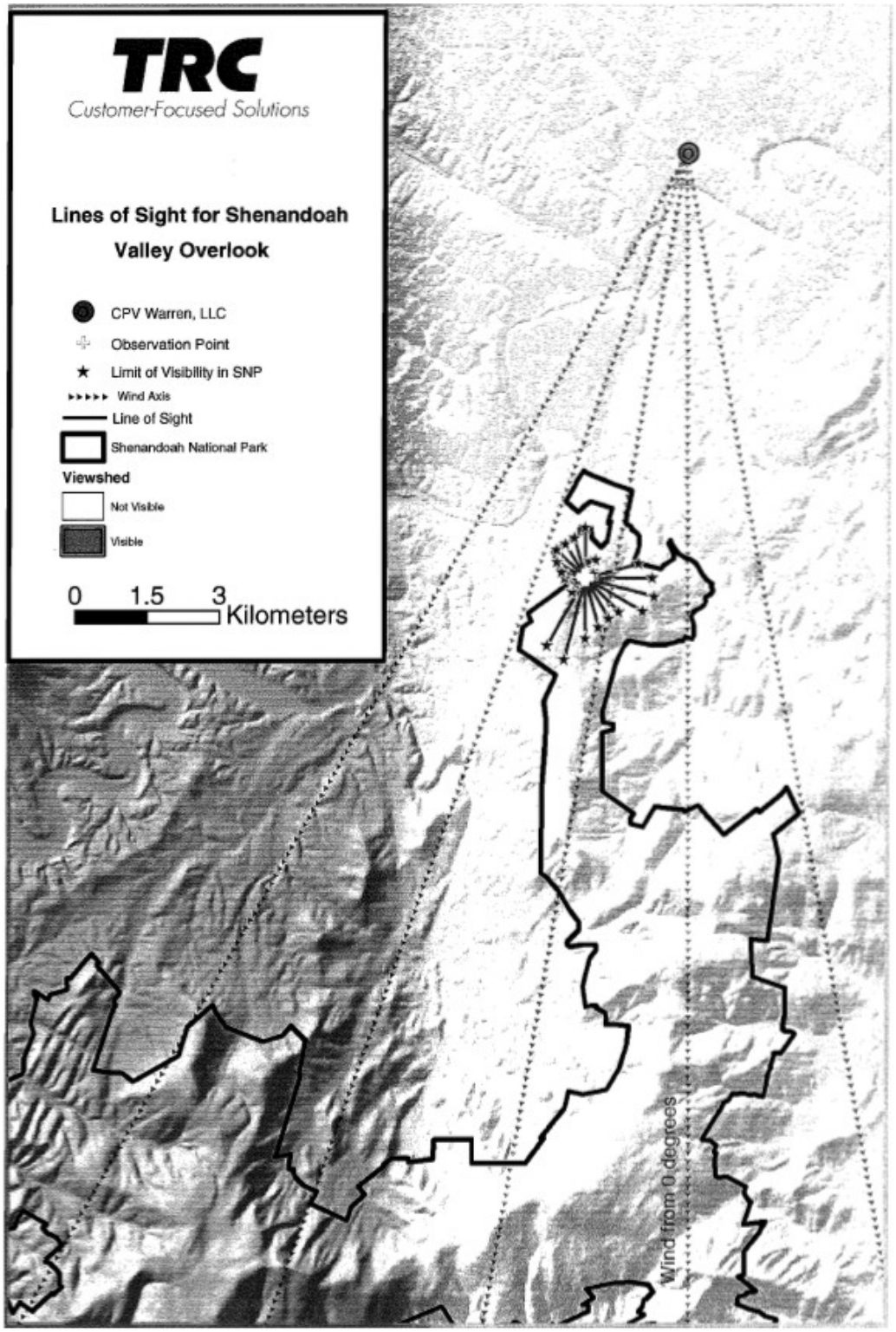


Figure 8-6 Lines of Sight for Dickey Ridge Visitor Center

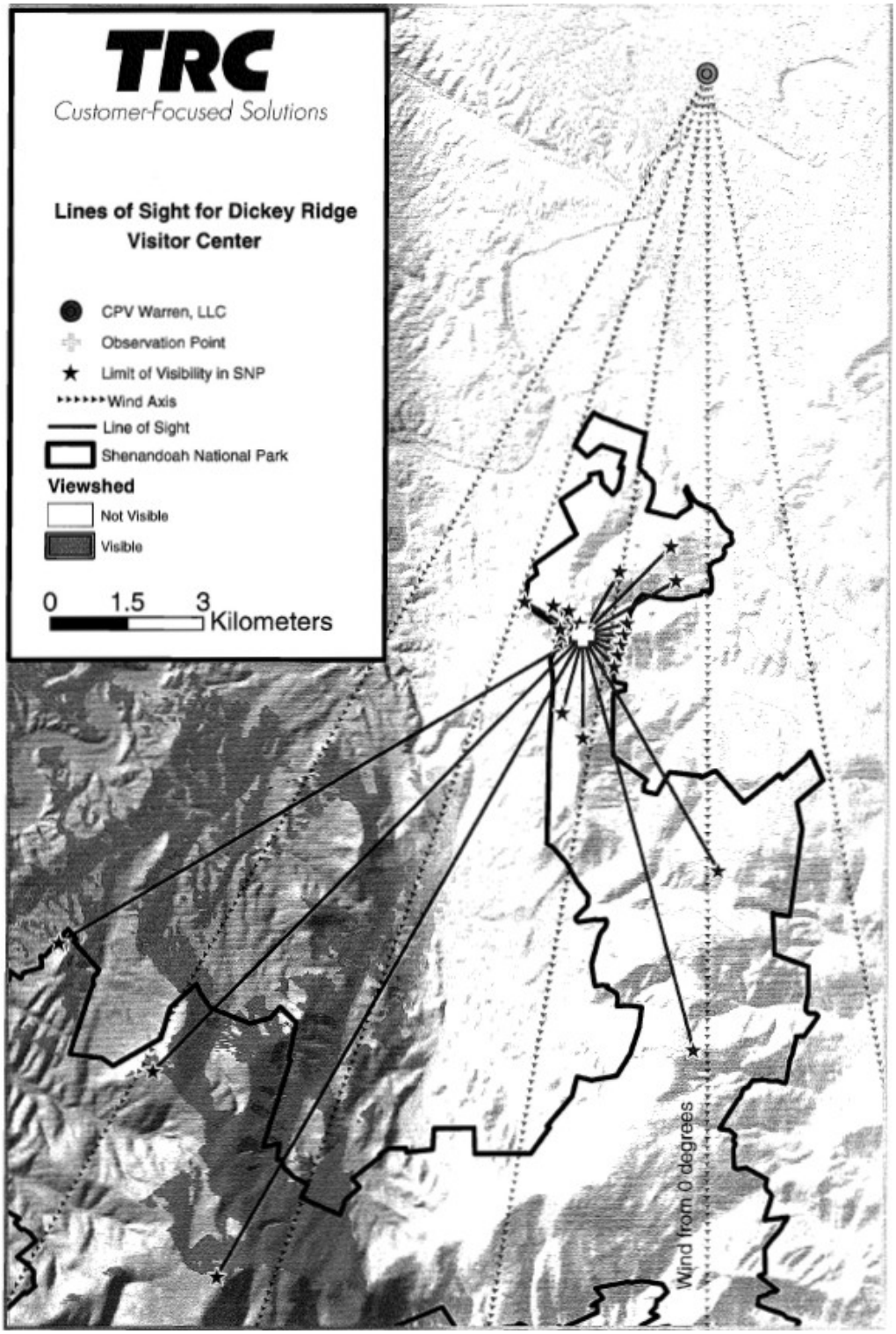


Figure 8-7 Lines of Sight for Signal Knob

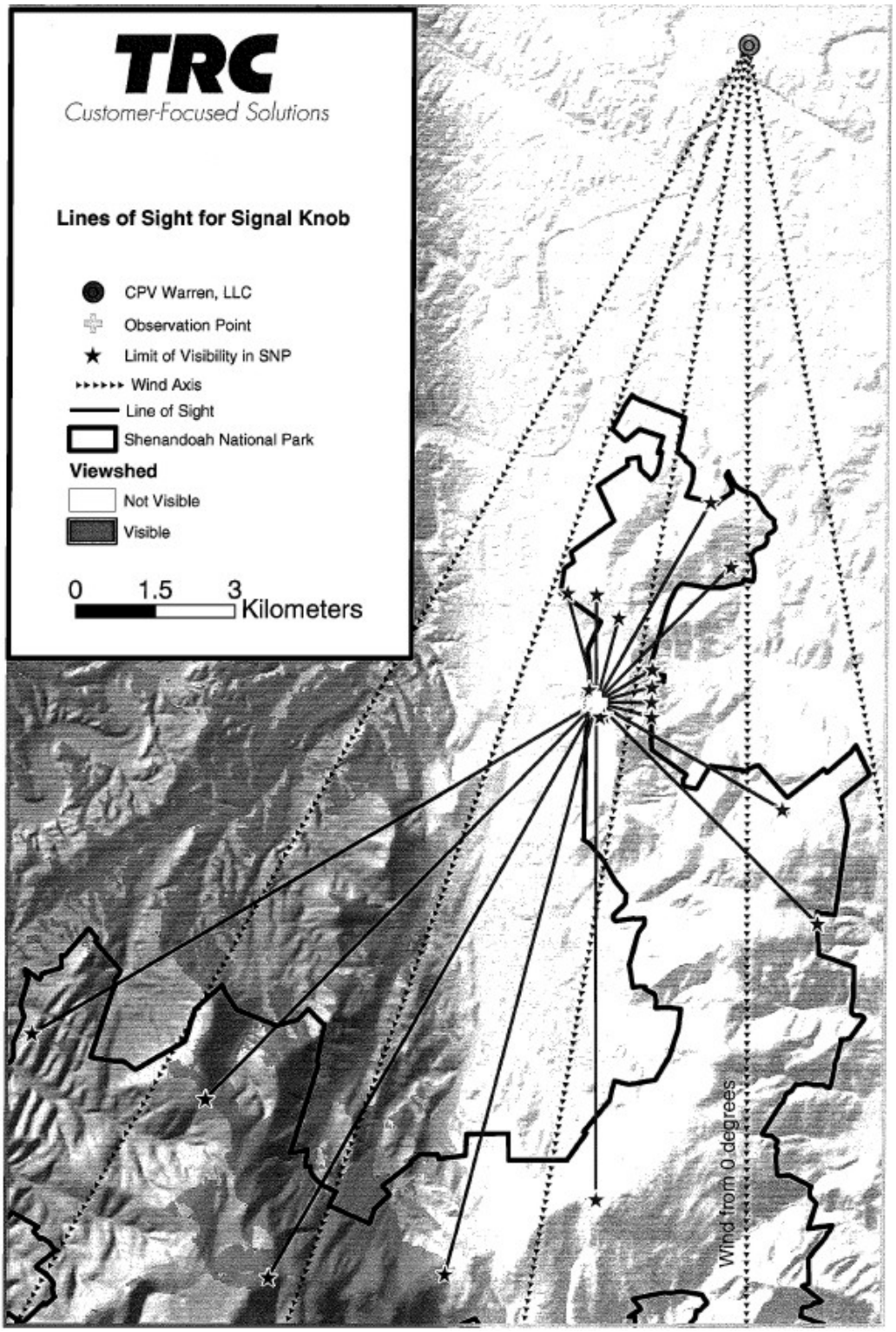


Figure 8-8 Lines of Sight for Compton Gap

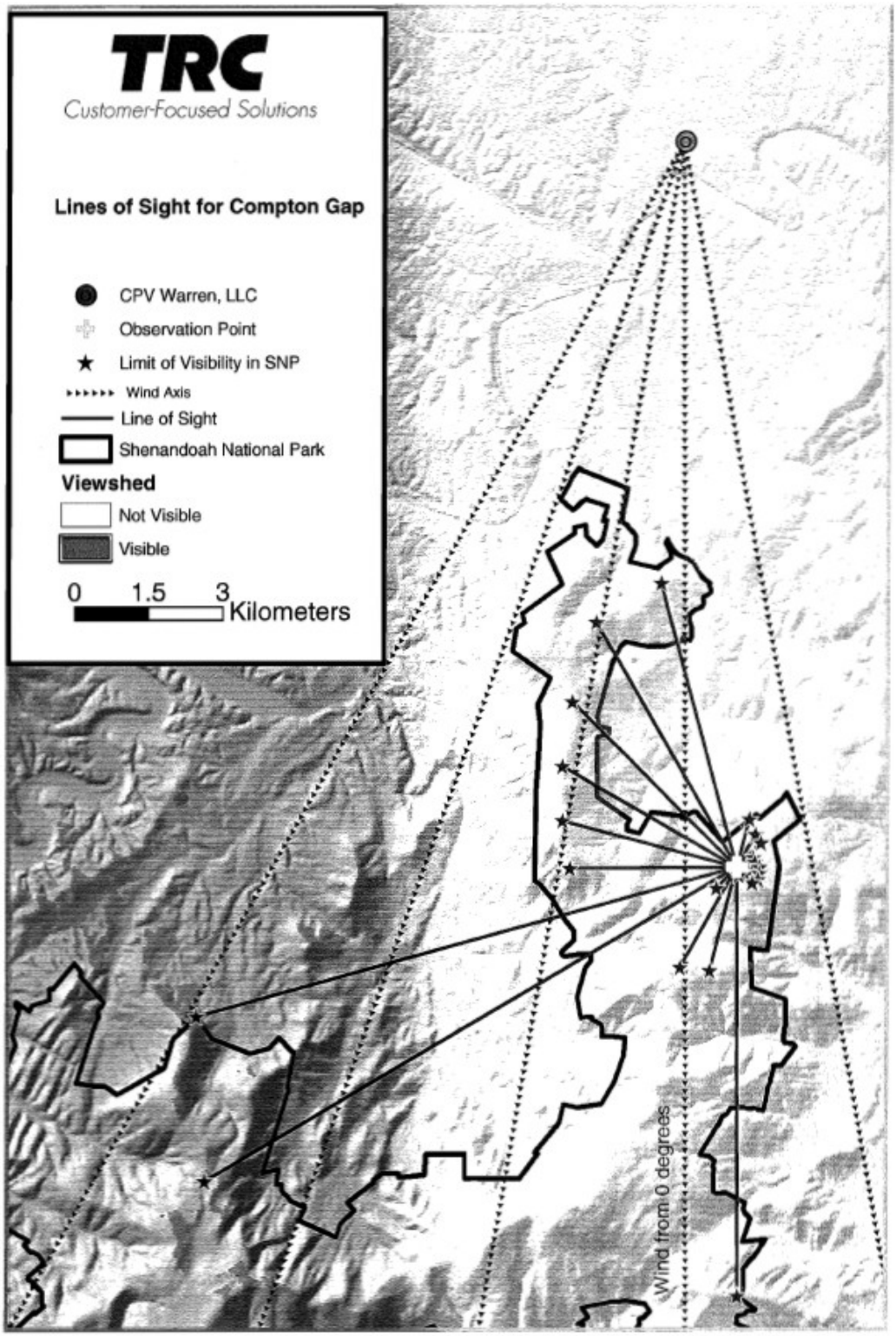


Figure 8-9 Lines of Sight for Lands Run Road Gate

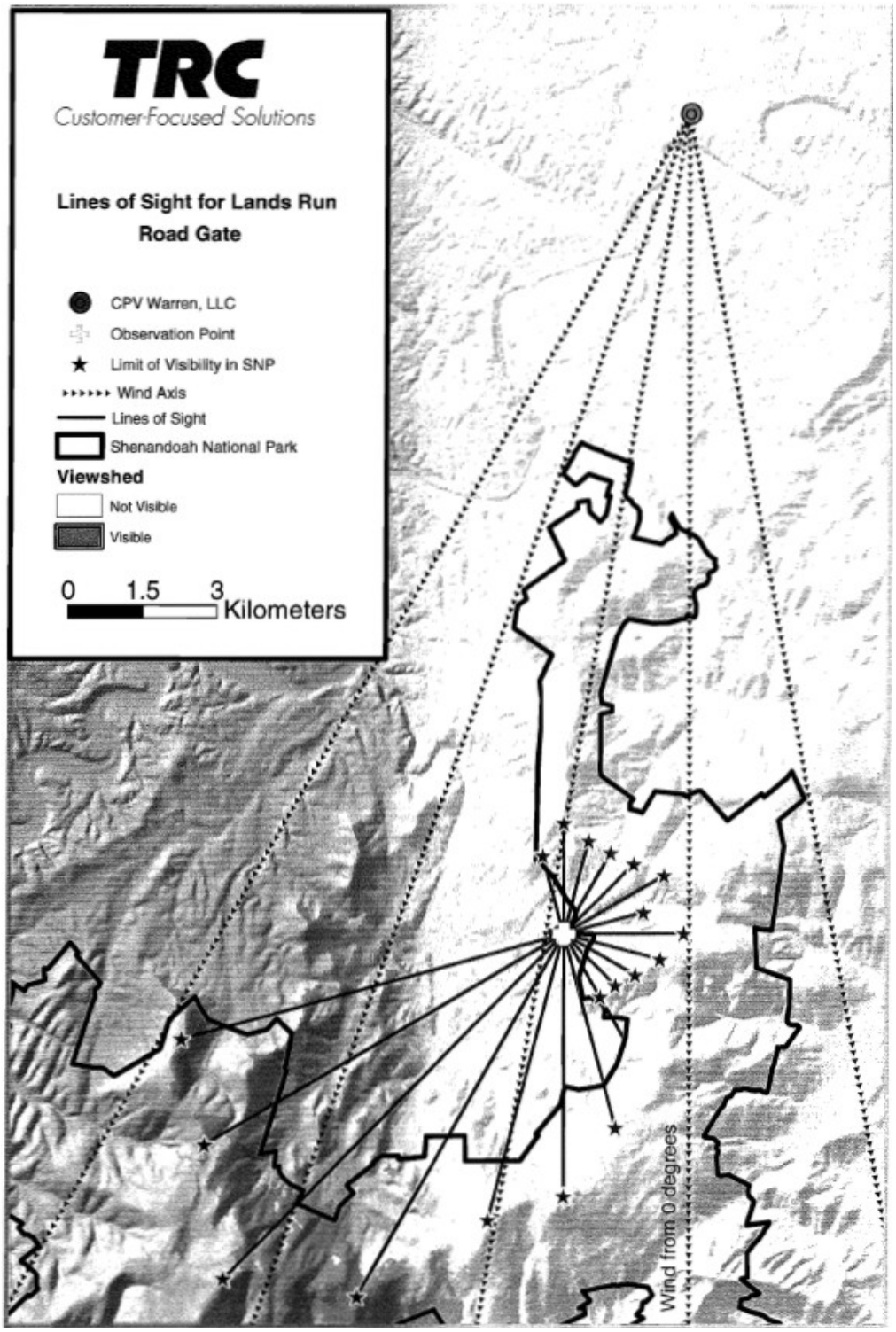


Table 8-8 Number of Excursion Hours for Each Viewpoint Using FLAG Visibility Thresholds

Predicted Number of Excursion Hours over 5 Years (at least one visibility parameter exceeding significance threshold) 3 Gas-Fired Turbines						
Wind from (degrees) -->	**0**	**10**	**20**	**30**	**Total**	**Percentage of Daytime Hours (%)**
Shenandoah Valley Overlook	5	*	*	0	5	0.02%
Dickey Ridge	94	*	*	0	94	0.43%
Signal Knob Overlook	99	*	*	16	115	0.52%
Compton Gap Road	*	32	16	2	50	0.23%
Lands Run Road Gate	*	*	26	0	26	0.12%
Excursion Hours**	114	32	27	16	189	

* Indicates that results for the given wind direction and view point were not taken into account because the view point is within 10° of the downwind axis of the source.

** Number of non-overlapping hours with a parameter excursion at one or more observation points

Table 8-9 Distribution of Excursion Hours for |C| and ΔE

Predicted Number of Excursion Hours over 5 Years (|C| or ΔE for sky or terrain exceeding significance threshold) 3 Gas-Fired Turbines											
Observation Point -->	**Compton Gap Road**			**Dickey Ridge**		**Signal Knob Overlook**		**Lands Run**		**Shenandoah Valley Overlook**	
Wind from degrees/north -->	**10**	**20**	**30**	**0**	**30**	**0**	**30**	**20**	**30**	**0**	**30**
Hours with Contrast Excursions											
Sky Background	3	0	0	2	0	3	0	5	0	5	0
Terrain Background	32	16	2	94	0	99	16	26	0	0	0
Contrast Total	32	16	2	94	0	99	16	26	0	5	0
Hours with delta E Excursions											
Sky Background	0	0	0	7	0	9	0	5	0	4	0
Terrain Background	15	5	1	22	0	36	11	15	0	0	0
Delta E Total	15	5	1	25	0	36	11	16	0	4	0
Total Excursion Hours	32	16	2	94	0	99	16	26	0	5	0

Table 8-10 Refined Number of Excursion Hours for Each Viewpoint Accounting for Realistic Visibility Parameter Thresholds

Predicted Number of Excursion Hours over 5 Years based on the Apparent Plume Width (at least one visibility parameter exceeding significance threshold) 3 Gas-Fired Turbines						
Wind from (degrees) -->	**0**	**10**	**20**	**30**	**Total**	**Percentage of Daytime Hours (%)**
Shenandoah Valley Overlook	3	*	*	0	3	0.01%
Dickey Ridge	16	*	*	0	16	0.07%
Signal Knob Overlook	27	*	*	2	29	0.13%
Compton Gap Road	*	13	4	0	17	0.08%
Lands Run Road Gate	*	*	8	0	8	0.04%
Excursion Hours**	33	13	8	2	56	

* Indicates that results for the given wind direction and view point were not taken into account because the view point is within 10° of the downwind axis of the source.

** Number of non-overlapping hours with a parameter excursion at one or more observation points

8.6 Acidic Deposition Analysis

The results of the Tier 1 deposition analysis for sulfur resulted in a low impact of about 0.008 kg/ha-yr, less than the Analysis Threshold (DAT) of 0.01 kg/ha-yr for the Eastern United States. The results of the Tier 1 acidic deposition analysis for nitrogen resulted in higher impacts, as expected, because NO_x emission rates are much greater than SO_2. The peak AERMOD impacts are relatively close to the source (within an hour's transport), but the conversion rate of NO_2 to nitric acid is only a few percent. The Tier 2 analysis resulted in a peak nitrogen deposition rate of about 0.04 kg/ha-yr, which is about 4 times the screening nitrogen DAT of 0.01 kg/ha-yr for the Eastern United States. As discussed below, the area covered by this peak deposition rate is quite small.

An important study[4] of the sensitivity of Shenandoah National Park ("SHEN") to acid deposition published by the National Park Service in 2006 facilitates the interpretation of the results of the acidic deposition analysis. This study, which is available at http://www.nps.gov/nero/science/FINAL/SHEN_acid_dep/SHEN_acid_dep.htm, indicates that the northern portion of Shenandoah National Park where the modeled nitrogen deposition is greatest may be less sensitive to acid than the central and southern portions of the park. The key excerpts from this study follow:

> Four categories of concern were adopted for soil and surface water conditions in SHEN: 1) *Low Concern*; 2) *Moderate Concern*; 3) *Elevated Concern*; and 4) *Acute Concern*. While the same

[4] Cosby, B.J., J.R. Webb, J.N. Galloway, and F. A. Deviney, 2006. Acidic Deposition Impacts on Natural Resources in Shenandoah National Park. Technical Report NPS/NER/NRTR—2006/066. Available at http://www.nps.gov/nero/science/FINAL/SHEN_acid_dep/SHEN_acid_dep.htm.

category names were used for maps of adverse effects on both surface water and soils, the biological effects for each category are specific to either aquatic or terrestrial ecosystems.

Concern for Adverse Effects of Acid Deposition on Aquatic Ecosystems in Shenandoah National Park

The categories of concern for surface water conditions are based on stream water Acid Neutralizing Capacity (ANC) and include a number of observed effects for a number of aquatic organisms in SHEN.

Low Concern. (Average ANC greater than 100 µeq/L). Reproducing brook trout populations expected where habitat is suitable. Fish species richness probably unaffected. Diversity and/or evenness of aquatic macroinvertebrate communities unaffected. Number of families and/or number of individuals of aquatic insects unaffected.

Moderate Concern. (Average ANC in the range 50–100 µeq/L). Reproducing brook trout populations expected where habitat is suitable. Fish species richness much reduced. Diversity and/or evenness of aquatic macroinvertebrate communities begin to decline. Number of families and/or number of individuals of aquatic insects begin to decline.

Elevated Concern. (Average ANC in the range 0–50 µeq/L). Brook trout populations sensitive and variable, lethal and sub-lethal effects possible. Fish species richness much reduced. Diversity and/or evenness of macroinvertebrate communities decline markedly. Number of families of aquatic insects declines markedly. Number of individuals in most aquatic insect families declines markedly. Number of individuals of acidophilic aquatic insect families increases sharply.

Acute Concern. (Average ANC less than 0 µeq/ L). Lethal effects on brook trout populations probable. Complete extirpation of fish populations expected (species richness equal zero). Extremely low diversity and/or evenness of aquatic macroinvertebrates communities. Extremely reduced number of families of aquatic insects. Extremely reduced numbers of individuals of most aquatic insect families. Large numbers of individuals of acidophilic aquatic insect families.

The categories of concern for soils are somewhat problematic in that direct observations of adverse effects of acidification are lacking in SHEN for terrestrial organisms. Nonetheless, there exist strong correlations between soil base saturation (BS) and measures of base cation availability for both forests and streams in SHEN. Because the relationships for effects of soil acidification are weaker than for surface waters, the expected effects for each category are less specific than for surface waters, but nonetheless represent best current knowledge.

Low Concern. (Average soil BS greater than 20%). No effects. Base cation availability for forests and surface waters not affected.

Moderate Concern. (Average soil BS in the range 10–20%). Moderate effects probable. Base cation availability for forests reduced and forest growth probably slowed. Base cation availability for surface waters reduced and moderate effects on aquatic biota expected (lowered stream water ANC).

Elevated Concern. (Average soil BS in the range 5–10%). Moderate effects certain and severe effects probable. Base cation availability for forests greatly reduced with resultant risk of mortality from various stresses (particularly if the base saturation was previously above 10% during the life of the tree). Base cation availability for surface waters greatly reduced producing sharp declines in stream water ANC (particularly during storm events) and resultant moderate to severe effects on stream water biota.

Acute Concern. (Average soil BS less than 5%). Severe effects certain. High risk of forest

mortality from various stresses including direct- acidification effects on roots and seedlings. Surface water ANC's are likely to be in the range of severe biological effects (certainly episodically and perhaps chronically).

Stream water ANC, pH, and base cation concentrations in SHEN are strongly correlated with bedrock geology. SHEN landscape includes three major bedrock types, siliceous (quartzite and sandstone), felsic (granitic), and mafic (basaltic).

Sulfate is the major strong-acid anion present in most SHEN streams. Nitrate concentrations are generally negligible, except in association with forest defoliation by the gypsy moth.

The three bedrock classes are mapped in Figure 8-10 (Figure 1.2 in the NPS report), and the figure shows that the northern portion of the park features mafic bedrock, which is the least susceptible to acidification effects.

Figures 8-11 and 8-12 show the areas of concern in Shenandoah National Park for acidification effects upon stream conditions and soils, respectively. These figures indicate that for areas in SHEN within 14 km of the proposed project, there is "low concern" for acidification effects on streams and soils. Beyond 14 km, there is a "moderate concern" for acidification effects.

Figures 8-13 and 8-14 show that the peak AERMOD NO_2 prediction occurs at a distance of about 9 km from the proposed project site, and that the predicted concentration drops off substantially at a distance of 14 km, such that the Tier 2 deposition analysis would indicate predicted nitrate deposition below the DAT. Therefore, we conclude that the project's nitrogen deposition effects will not adversely affect the Shenandoah National Park.

An additional analysis is provided in Appendix J that computes the change in the ANC in 9 identified watersheds (from the National Park Service 2006 report) within 50 km of the proposed project. This analysis shows that all identified areas have a baseline ANC of at least 25 µeq/l, and a conservative ANC change is about 2%, well below the 10% change level of concern. Therefore, this additional information indicates that the project would likely not cause an adverse deposition impact in Shenandoah National Park.

Figure 8-10 Watersheds in Shenandoah National Park in Relation to Major Bedrock Classes

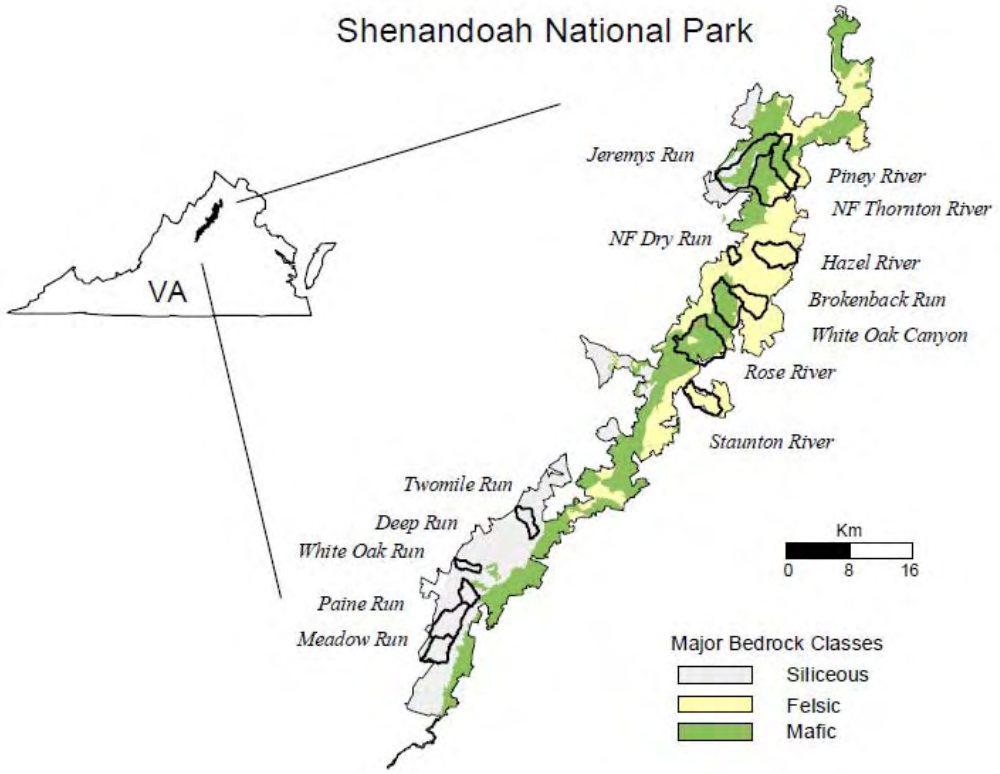


Figure 8-11 Areas of Concern for Adverse Effects from Acidic Deposition on Surface Water Conditions in Shenandoah National Park

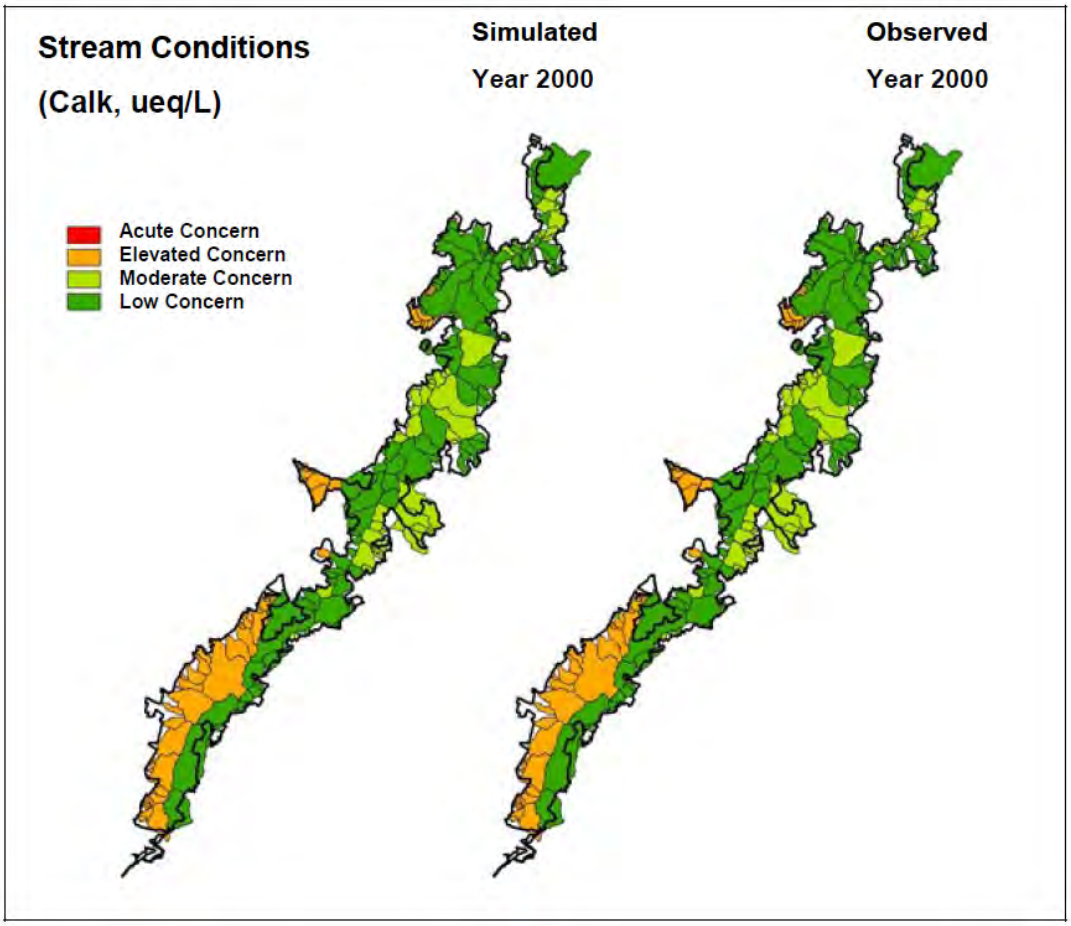


Figure 8-12 Areas of Concern for Adverse Effects from Acidic Deposition on Soil Conditions in Shenandoah National Park

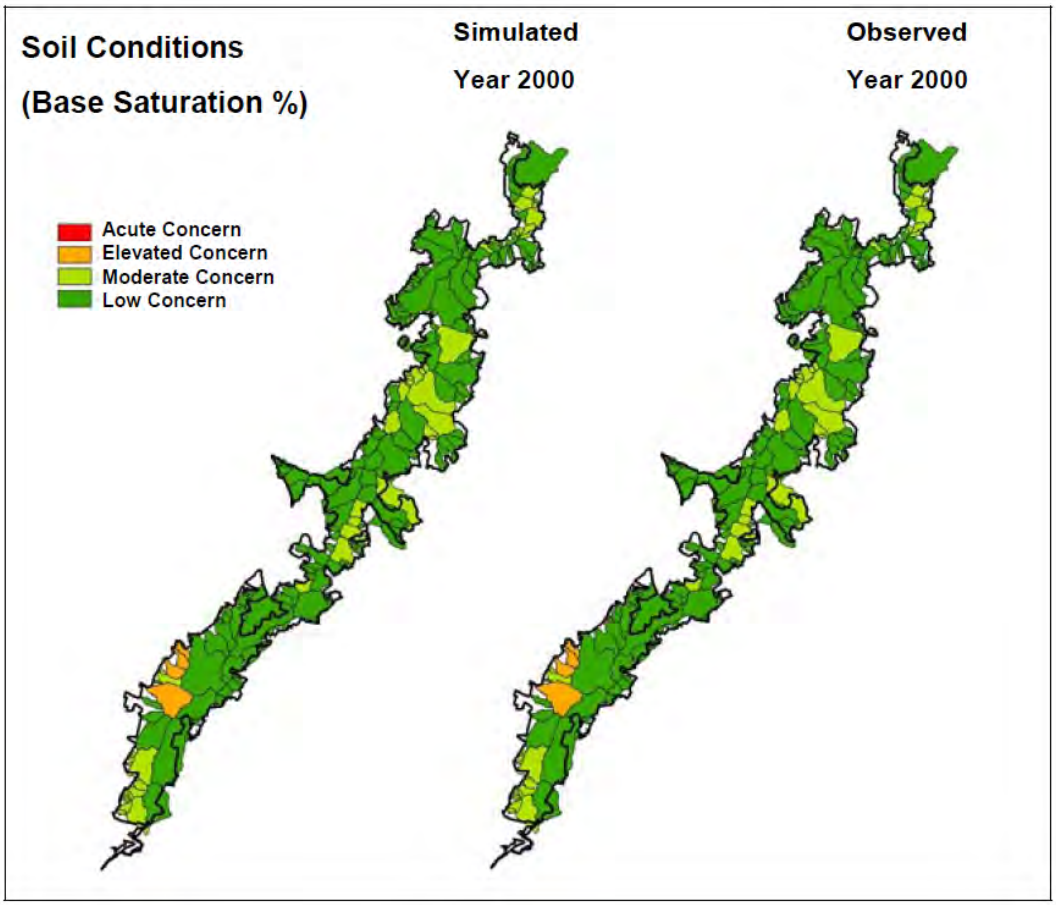


Figure 8-13 Isopleths of Annual NO_2 Concentrations Predicted for the Proposed Project Emissions

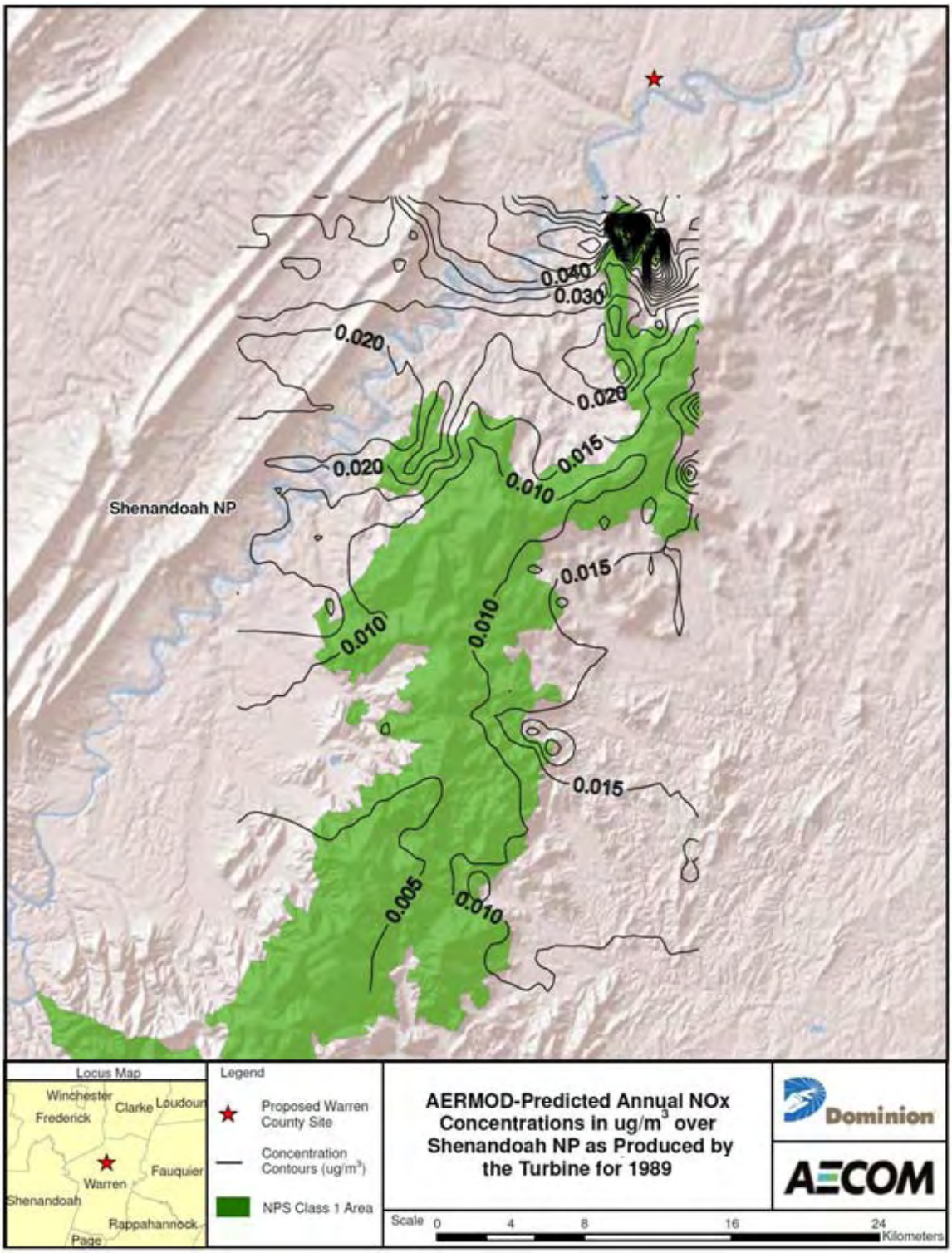
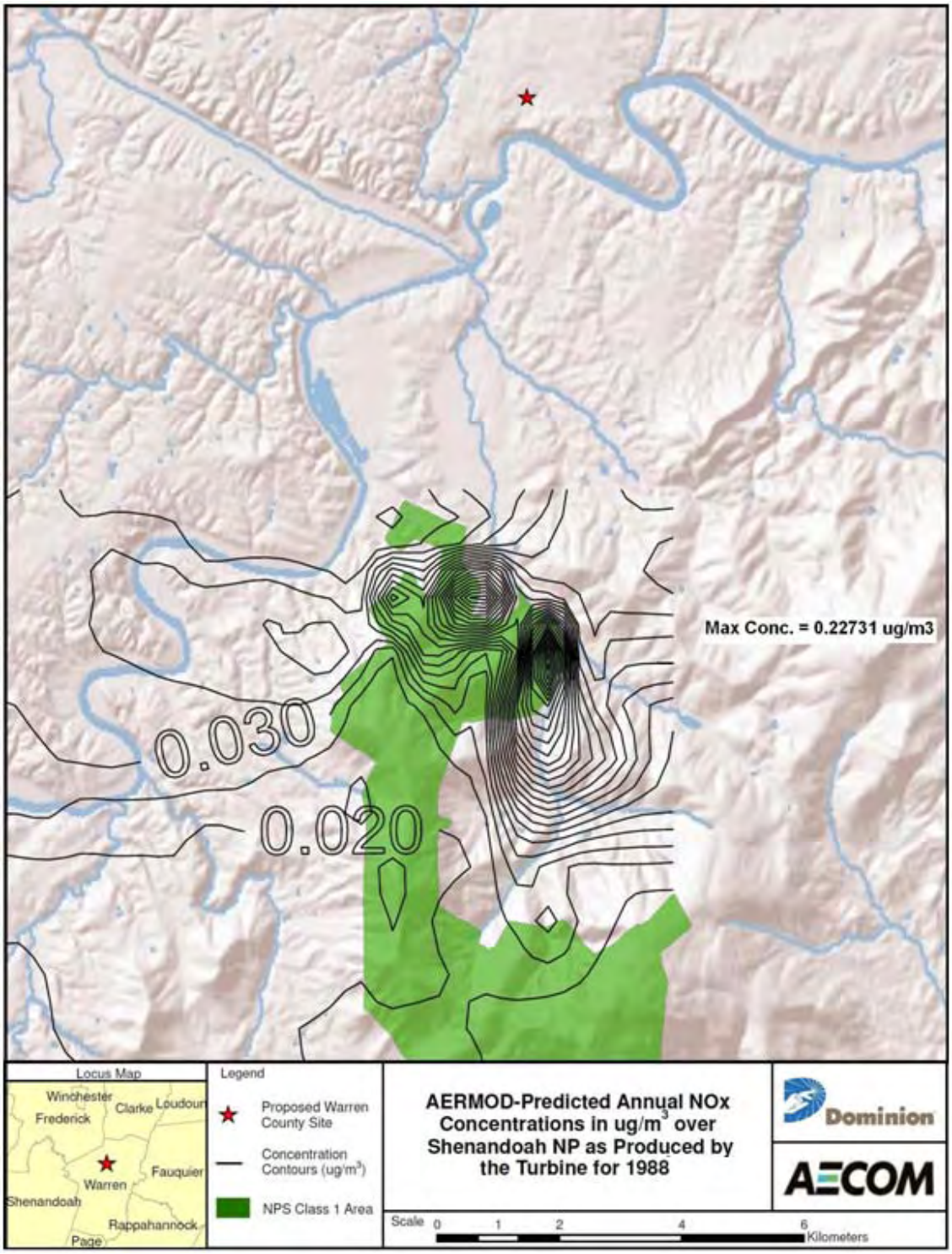


Figure 8-14 Zoomed in Version of the Isopleths of Annual NO_2 Concentrations Predicted for the Proposed Project Emissions



8.7 Summary of Class I Area Assessment

The AERMOD modeling of project emissions of NO_2 and PM_{10} indicate that the Project will have a significant impact within Shenandoah National Park for these two pollutants. Therefore, a cumulative modeling analysis was conducted, using a nearby emission source inventory provided by Virginia and West Virginia.

Plume visibility modeling using PLUVUE II, conducted with procedures consistent with those used in previous permitting, indicated that the likelihood of visible plumes is insignificant, well less than a one percent probability for each observer point.

Acidic deposition results for nitrogen indicate that there is a limited area for which the deposition exceeds the screening thresholds. However, in that area, the stream and soil conditions are of “low concern” for acidification effects. Therefore, we conclude that the potential nitrogen deposition effects will not be adverse.

9.0 Other Air Quality Issues

The preceding sections of the PSD permit application have focused on demonstrating that the proposed facility will incorporate Best Available Control Technology and will not have significant criteria pollutant air quality impacts in Class II areas. PSD regulations also require review of additional air quality items as part of an application for a permit to construct. The following section discusses considerations of impacts that could result from the proposed project with respect to the following:

- Associated Growth
- Vegetation and Soils
- Toxic Air Pollutant Analysis
- Visible Plume Analysis

9.1 Associated Growth

A growth analysis examines the potential emissions from secondary sources associated with the proposed project. While these activities are not directly involved in project operation, the emissions involve those that can reasonably be expected to occur; for instance, industrial, commercial, and residential growth that will occur in the Project area due to the Project itself. Secondary emissions do not include any emissions which come directly from a mobile source, such as emissions from the tailpipe of any on-road motor vehicle or the propulsion of a train (USEPA 1990). They also do not include sources that do not impact the same general area as the source under review.

The work force expected for the Project will range from 400 to 600 jobs during various phases of construction. It is expected that a significant regional construction force is already available to build the Project. Therefore, it is expected that no new housing, commercial or industrial construction will be necessary to support the Project during the two-year construction schedule. The Project will also require approximately 20 to 25 permanent positions. Individuals that already live in the region will perform a number of these jobs. For any new personnel moving to the area, no new housing requirements are expected. Further, due to the small number of new individuals expected to move onto the area to support the Project and existence of some commercial activity in the area, new commercial construction will not be necessary to support the Project's permanent work force. In addition, no significant level of industrial related support will be necessary for the Project, thus industrial growth is not expected.

Based on the growth expectations above, no new significant emissions from secondary growth during Project construction and operation are anticipated.

9.2 Vegetation and Soils

The screening methodology provided in the EPA's guidance document for soils and vegetation, "*A Screening Procedure for the Impacts of Air Pollution Sources on Plants, Soils, and Animals (EPA 450/2-81-078)",* was supplemented with a more robust soils and vegetation analysis for the proposed project.

Vegetation Analysis

As an indication of whether emissions from the proposed project will significantly impact the surrounding vegetation (i.e., cause acute or chronic exposure to each evaluated pollutant), the modeled emission concentrations were compared against both a range of injury thresholds found in various peer-reviewed research articles that specifically examine effects of different pollutants on vegetation as well as established National Ambient Air Quality Standard (NAAQS) secondary standards. Since the NAAQS secondary standards were set to protect public welfare, including protection against damage to crops and vegetation, comparing the modeled emissions to these standards provides an indication as to whether potential impacts are likely to be significant. However, given that secondary standards for some criteria pollutants are under review, comparison to the secondary NAAQS may not be definitive. Contribution to the deposition of nitrogen (N) in the Shenandoah National Park was discussed in Section 8.6.

For the vegetation analysis, modeled concentrations of NO_x, PM_{10}, and CO were compared against the vegetation sensitivity thresholds listed in the aforementioned 1980 EPA guidance, secondary NAAQS, and plant injury thresholds found in the literature. Table 9-1 illustrates injury threshold ranges determined through a review of readily available research. The same meteorological data and Cartesian grid (20-km extent) as described in Section 6 was used for the vegetation analysis. Please not e that the receptor grid was not refined for any criteria pollutant for the vegetation analysis. As shown in Table 9-2, the results clearly indicate that no adverse impacts will occur to sensitive vegetation as a result of operation of the proposed project. In Section 8.6, the N deposition fluxes resulting from the proposed project were evaluated.

Table 9-1 Injury Threshold for Vegetation

Pollutants	Injury Threshold (Dose) ($\mu g/m^3$) (1)	NAAQS ($\mu g/m^3$)	EPA's 1980 Screening Concentration ($\mu g/ m^3$) (2)
NO_x (as NO_2)	940 (1 hour) 280 (annual)	100 (annual)	94 (annual)
			3,760 (4 hour)
			564 (1 month)
PM (as PM_{10})	See NAAQS	150 (24 hour)	None
		50 (annual; revoked in 2006 but retained for this analysis)	
CO	None		1,800,000 (weekly)

(1) Values, suggested in the Spiritwood Station PSD permit application; see http://www.greatriverenergy.com/makingelectricity/newprojects/spiritwood_applicationsandreports.html

(2) "A Screening Procedure for the Impacts of Air Pollution Sources on Plants, Soils, and Animals". EPA 450/2-81-078, December 1980

Table 9-2 Comparison to EPA Criteria for Gaseous Pollutant Impacts on Natural Vegetation and Crops

Pollutant	Averaging Period	Maximum Impact of Proposed Facility ($\mu g/m^3$)	Minimum Impact Level for Effects On Sensitive Plants ($\mu g/m^3$) (1)
NO_X	1-hour(3)	342.97	940
	4-hour	73.56	3,760
	1-month	1.12	564
	Annual	0.60	94
PM_{10}	24-Hour	5.00	150
	Annual	0.41	50
CO	1-week(2)	7.65	1,800,000

(1) Minimum Impact is the lowest threshold found in Table 9-1.
(2) 24-hour average used to conservatively represent 1 week average impact.
(3) Please note the 1-hour NO_2 concentration is the highest modeled concentration over the 5 modeled years. This is not consistent with how the new 1-hour NO_2 NAAQS is defined.

Soil assessment

To determine whether the Project emissions could adversely affect the soil in the vicinity of the Project, the type of soil surrounding the Project site was reviewed. The soil type was determined from data collected from the U.S. Department of Agriculture, National Resource Conservation Service's (NRCS), Soil Survey Geographic (SSGUGO) database[5] and the NRCS Web Soil Survey tool[6]. In addition, descriptions of soil type within Shenandoah National Park from the National Park Service's Technical Report, *Acidic Deposition Impacts on Natural Resources in Shenandoah National Park*, were reviewed. Aside from Shenandoah National Park, soil types within adjacent Warren, Clarke, Frederick and Shenandoah Counties were examined. Our evaluation indicates that for Warren County, the predominant soil types are a variety of silt and stony loams. In Clarke County, the predominate soil types are a mixture of silt and sandy loams and rocky outcrops with Frederick County containing a mixture of silt and gravely/cobbly loams with some areas of fine sandy loams. In Shenandoah County, the predominate soil types are also a mixture of silt, clay, cobbly and sandy loams. Finally, our evaluation indicates that the Shenandoah National Park contains a variety of silt

[5] U.S. Department of Agriculture, National Resource Conservation Service's (NRCS), Soil Survey Geographic (SSGUGO) database . Accessed 17 December 2009. http://soils.usda.gov/survey/geography/ssurgo/

[6] U.S. Department of Agriculture, National Resource Conservation Service's Web Soil Survey Tool. Accessed 17 December 2009. http://weboilsurvey.nrcs.usda.gov/app/HomePage.htm

and sandy loams, along with colluvial fans, talus deposits, and exposed rock. Soils in the park originate predominately from the weathering of bedrock or the transport of weathered material from upslope material.

The most important aspect of the Project's impact upon soils is the effect of acidic deposition, as discussed in Section 8.6. That discussion indicates that the type of bedrock in the northern portion of the Shenandoah National Park is of relatively low concern to the National Park Service for acidic effects.

An area of approximately 10,000 acres in size comprising the northern portion of the Shenandoah National Park using the NRCS Web Soil Survey tool (see Figure 9-1) shows that the area is predominately composed of silt and silt-clay loam. Silt and clay loams are considered to have a moderate to high buffering capacity, thus having a higher capacity to absorb acidic deposition without changing the soil pH.[7] A similar sized area of interest centering around the proposed project site indicates soil composition similar to what was found in the area around the northern reaches of the Shenandoah National Park. Predominate soil type is silt loam, with areas of rock outcrops. A comparison of soil types within the Shenandoah National Park area of interest and the project site is provided in Table 9-3. Given the relatively low emissions due to the proposed project, and because the soil types immediately around the proposed project site and within the northern reaches of the Shenandoah National Park (where the NPS report indicates areas of low concern regarding soil) are similar, no adverse impacts on soils due to Project emissions are anticipated.

[7] Murphy, Stephanie Ph.D., Rutgers Soil Testing Laboratory, New Jersey Agricultural Experiment Station. "Soil pH and Lime Requirements for Home Grounds Plantings".

Figure 9-1 Soil Evaluation Areas of Interest

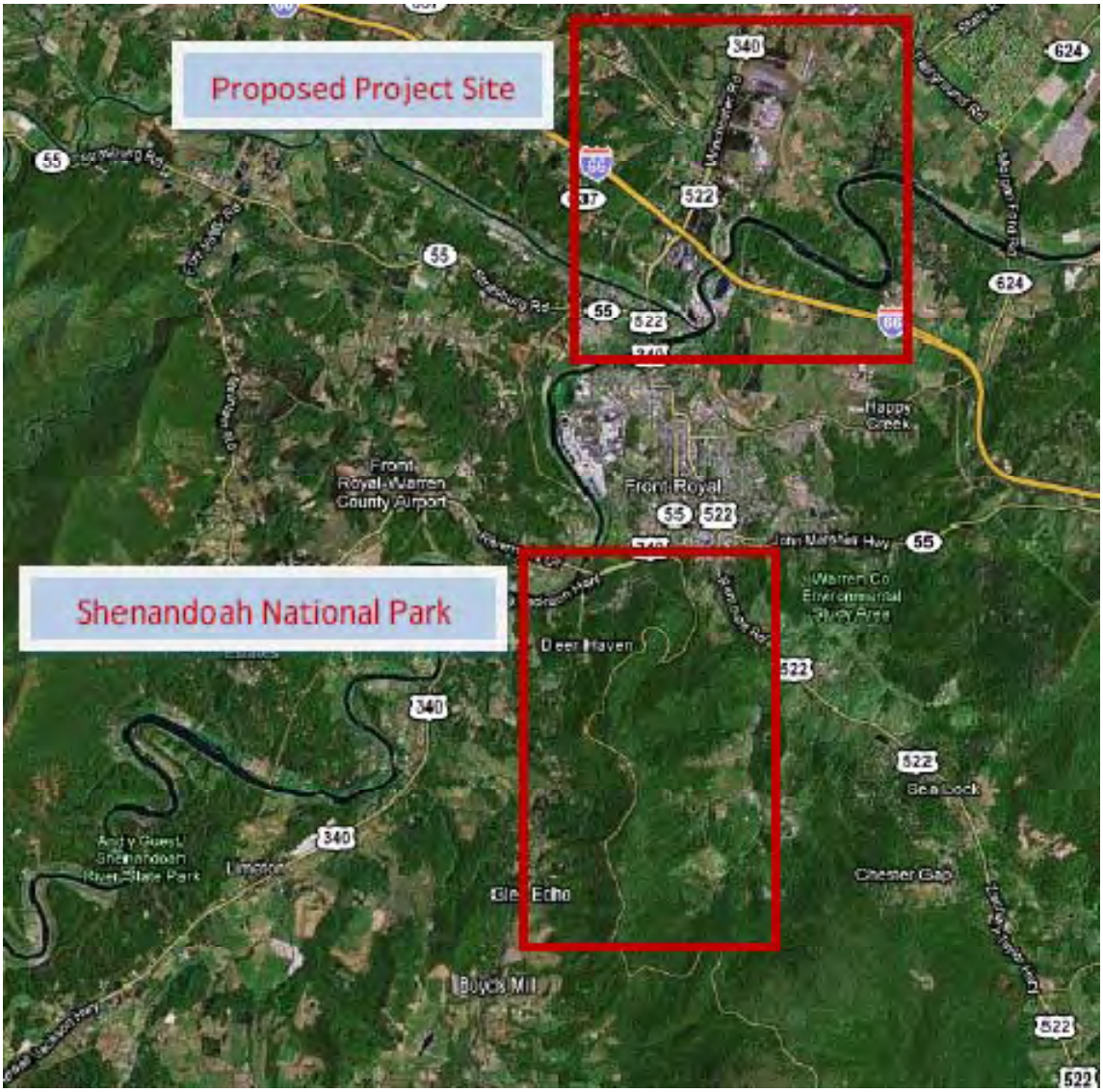


Table 9-3 Buffering Capacity of Soils Around Project Site and Northern Shenandoah National Park

	Project Site (% in area of interest)	Shenandoah National Park (% in area of interest)
High and Moderate Buffering Capacity Soils	**94.1**	**95**
High Buffer Capacity (Clay Loams)		
Silty clay loam	7.3	30.9
TOTAL	**7.3**	**30.9**
Moderate Buffer Capacity (Sandy Loam, Loam, Silt Loam)		
Silt loam	77	46.8
Sandy loam	5.2	1.5
Loam	4.6	15.8
TOTAL	**86.8**	**64.1**
Low Buffer Capacity (Sand, Loamy Sand)		
Loamy sand	0.5	0
Cobbly loam	0	4.4
TOTAL	**0.5**	**4.4**
Other		
Pits, quarries, dumps, and water	5.4	0.4
TOTAL	**5.4**	**0.4**

9.3 Toxic Pollutant Analysis

In addition to predicting the ambient air concentrations of criteria pollutants, the concentrations of other pollutants from the Warren County Project emission sources regulated under VA DEQ air toxics program were evaluated.

Table 9-4 contains a listing of the potential emissions of HAP pollutants for the proposed Project. The emissions were estimated using emission factors (AP-42) and vendor data. In addition to the potential emission listing, the exemption levels for each pollutant are also listed in Table 9-4.

As shown in Table 9-4, all HAPS are exempt except for Acrolein, Cadmium, Chromium, Nickel and Formaldehyde. The same set of meteorological data and Cartesian grid (20-km extent) as described in Section 6 was used for the toxics analysis as well. Please note that the receptor grid was not refined for the toxic analysis as with the criteria pollutant analysis. The HAPs were modeled with the worst-case emission rate across all operating loads and impacts were compared to the VA DEQ State Ambient Air Concentrations (SAAC) presented in Table 9-5.

Table 9-4 Summary of HAP Emission Rates and VA DEQ Exemption Levels

Pollutant	Total HAP Emissions		Virginia Air Toxics Exemption Levels		Exempt? (hourly)	Exempt? (annual)
	Maximum Hourly (lb/hr)	Annual (tpy)	Maximum Hourly (lb/hr)	Annual (tpy)	Yes/No	Yes/No
1,3-Butadiene	2.79E-03	1.19E-02	1.452	3.19	Yes	Yes
2-Methylnaphthalene	2.80E-05	8.86E-05	-	-	Yes	Yes
3-Methylchloranthrene	2.10E-06	6.64E-06	-	-	Yes	Yes
7,12-Dimethylbenz(a)anthracene	1.87E-05	5.90E-05	-	-	Yes	Yes
Acenaphthene	8.45E-05	2.72E-05	-	-	Yes	Yes
Acenaphthylene	1.70E-04	4.86E-05	-	-	Yes	Yes
Acetaldehyde	2.54E-01	1.10E+00	8.91	26.1	Yes	Yes
Acrolein	4.06E-02	1.76E-01	0.02277	0.03335	No	No
Anthracene	2.79E-05	1.51E-05	-	-	Yes	Yes
Benz(a)anthracene	1.65E-05	1.02E-05	-	-	Yes	Yes
Benzene	9.32E-02	3.42E-01	2.112	4.64	Yes	Yes
Benzo(a)pyrene	6.18E-06	5.62E-06	-	-	Yes	Yes
Benzo(b)flouoranthene	2.11E-05	1.14E-05	-	-	Yes	Yes
Benzo(g,h,I)perylene	1.08E-05	6.78E-06	-	-	Yes	Yes
Benzo(k)fluoranthene	6.14E-06	7.65E-06	-	-	Yes	Yes
Chrysene	2.88E-05	1.33E-05	-	-	Yes	Yes
Dibenzo(a,h)anthracene	8.59E-06	6.23E-06	-	-	Yes	Yes
Dichlorobenzene	1.40E-03	4.43E-03	21.813	65.395	Yes	Yes
Ethylbenzene	2.01E-01	8.82E-01	17.919	62.93	Yes	Yes
Fluoranthene	8.91E-05	3.25E-05	-	-	Yes	Yes
Fluorene	2.87E-04	8.12E-05	-	-	Yes	Yes
Formaldehyde (g)	1.48E+00	6.34E+00	0.0825	0.174	No	No
Hexane	2.10E+00	6.64E+00	11.616	25.52	Yes	Yes
Indeno(1,2,3-cd)pyrene	9.96E-06	8.61E-06	-	-	Yes	Yes
Naphthalene	1.13E-02	3.87E-02	2.607	7.54	Yes	Yes
PAHs	1.38E-02	6.06E-02	-	-	Yes	Yes

Pollutant	Total HAP Emissions		Virginia Air Toxics Exemption Levels		Exempt? (hourly)	Exempt? (annual)
	Maximum Hourly (lb/hr)	Annual (tpy)	Maximum Hourly (lb/hr)	Annual (tpy)	Yes/No	Yes/No
Phenanathrene	7.77E-04	2.52E-04	-	-	Yes	Yes
Propylene Oxide	1.82E-01	7.99E-01	3.168	6.96	Yes	Yes
Pyrene	7.95E-05	3.69E-05	-	-	Yes	Yes
Toluene	8.27E-01	3.60E+00	18.645	54.665	Yes	Yes
Xylene	4.07E-01	1.76E+00	21.483	62.93	Yes	Yes
Arsenic	2.08E-03	1.00E-03	0.0132	0.029	Yes	Yes
Beryllium	1.25E-04	6.02E-05	0.000132	0.00029	Yes	Yes
Cadmium	1.15E-02	5.51E-03	0.0033	0.00725	No	Yes
Chromium	1.46E-02	7.02E-03	0.0033	0.00725	No	Yes
Cobalt	8.75E-04	4.21E-04	0.0033	0.00725	Yes	Yes
Lead	5.21E-03	2.51E-03	0.0099	0.02175	Yes	Yes
Manganese	3.96E-03	1.91E-03	0.33	0.725	Yes	Yes
Mercury	2.71E-03	1.30E-03	0.0033	0.00725	Yes	Yes
Nickel	2.19E-02	1.05E-02	0.0066	0.0145	No	Yes
Selenium	2.50E-04	1.20E-04	0.0132	0.029	Yes	Yes

Table 9-5 Maximum Concentrations for Non-Exempt HAPs

HAP	Averaging period	Maximum Modeled Concentration ($\mu g/m^3$)	VA SAAC ($\mu g/m^3$)	Complies Yes/No
Acrolein	1 Hour	4.36E-02	17.25	Yes
	Annual	2.30E-04	0.46	Yes
Formaldehyde	1 Hour	1.58E+00	62.50	Yes
	Annual	9.24E-03	2.40	Yes
Cadmium	1 Hour	1.23E-02	2.50	Yes
Chromium	1 Hour	1.56E-02	2.50	Yes
Nickel	1 Hour	2.34E-02	5.00	Yes

9.4 Visible Plume Analysis

A visible plume assessment is required for proposed PSD projects within 50 km of a Class I area. As such, a refined visible plume impact assessment was performed using PLUVUE for Shenandoah National Park. This analysis is discussed in detail in Section 8.

It is not anticipated that the proposed project will have a adverse impact on visibility in Class II areas because there are no known integral vistas within 50 km of the proposed project source and the facility will have strict opacity limits which should limit the possibility of a visible plume impacting the surrounding Class II area.

However, at the request of VA DEQ, a screening modeling analysis was conducted to assess the potential for visual plume impacts at a Class II area within 50 km of the project site. Our review of National Parks in Virginia (see http://www.nps.gov/applications/parksearch/state.cfm?st=VA) indicated that the Appalachian Trail is the closest and only identified sensitive area outside Shenandoah National Park within 50 km of the project site. The project site is about 11 kilometers to the northwest of the closest approach of the Appalachian Trail. The visibility screening modeling approach followed guidance provided in USEPA's Workbook for Plume Visual Impact Screening and Analysis (Revised) (October 1992; EPA-454/R-92-023) ("Workbook"). As such, the VISCREEN model was applied to estimate two visual impact parameters, plume perceptibility (ΔE) and plume contrast (C_p). Screening-level guidance indicates that values above 2.0 for ΔE and +/- 0.05 for C_p are considered perceptible.

The Workbook offers two levels of analyses. A Level 1 screening analysis is the most simplified and conservative approach employing default meteorological data with no site-specific conditions. A Level 2 analysis takes into account representative meteorological data and site-specific conditions such as complex terrain. Initially, the Level 1 analysis was conducted and indicated ΔE and C_p values were above the screening thresholds of 2.0 and 0.5, respectively. Therefore, a Level 2 analysis was conducted.

The source data required by VISCREEN are total NO_X emissions (110.14 pounds per hour [lb/hr]) and particulate emissions (49.22 lb/hr) for the project. These emissions represent worst-case start-up/shutdown operations. In addition, plume visibility assessment was conducted for the normal operations (NO_X = 75.96 lb/hr and PM_{10} = 63.48 lb/hr). In both cases, these emissions represent composite worst-case hourly emissions over all turbine loads.

The 22.5 degree (°) wind direction sectors that would transport emissions from the project site toward the Appalachian Trail chosen for the analysis, along with the closest and farthest distances from the trail to the project site, are shown in Table 9-4. The location of the Appalachian Trail relative to the project site is shown in Figure 9-2.

Table 9-4 Level 2 Input Data

22.5° Wind Sector	Closest Distance to the Source (km)	Furthest Distance from the Source (km)	Level 2 Worst Case Stability Class	Level 2 Worst Case Wind Speed (m/s)
159.75 – 182.25	10.3	17.0	D	2

Based on this information, and the five years of meteorological data, a table of joint frequency of occurrence of wind speed, wind direction, and stability class was developed as outlined in the Workbook. The dispersion conditions, defined by wind speed and stability class, were ranked by evaluating the product of σ_y, σ_z, and u, where σ_y and σ_z are the Pasquill-Gifford horizontal and vertical diffusion coefficients for the given stability class and downwind distance and u is the wind speed. The dispersion conditions were then ranked in ascending order according to the value of $\sigma_y\sigma_z u$ as shown in Table 9-5.

According to the Workbook, VISCREEN is to be applied with the worst-case meteorological conditions that have a $\sigma_y\sigma_z u$ product with a cumulative probability of one percent. That is, the dispersion condition is selected such that the sum of all frequencies of occurrence of conditions worse than this condition totals one percent. Note that as recommended by the Workbook, dispersion conditions that result in greater than 12 hours of plume transport time are discounted from the analysis, since it is unlikely that steady-state plume conditions would persist for more than 12 hours.

According to Table 9-5, the worst-case daylight (6 AM – 6 PM) dispersion conditions with cumulative frequency of 1 percent are D stability, 2 m/sec. Therefore, VISCREEN was applied with D stability, 2 m/sec. As recommended by the Workbook, a visual range of 40 kilometers was used.

The VISCREEN results are summarized in Table 9-6 using start-up/shutdown and normal operations emissions. VISCREEN provides results of ΔE and C_p for both sky and terrain backgrounds inside the Class I area. The results are below the significance criteria. Therefore, the plume is expected to be imperceptible against background sky and terrain.

Table 9-5 Dispersion Condition Frequency Analysis

Dispersion Condition		$\sigma_y\sigma_z u$	Transport Time	Frequency By Time of Day (%)				Cumulative Frequency By Time of Day (%)			
Stability Class	**Wind Speed (m/s)**	**(m^3/s)**	**(hours)**	**0-6**	**6-12**	**12-18**	**18-24**	**0-6**	**6-12**	**12-18**	**18-24**
F	1	24811	9	2.455	0.11	0.018	1.433	2.455	0.11	0.018	1.433
F	2	49622	3	1.305	0.055	0.018	1.177	3.76	0.164	0.037	2.61
E	1	66028	9	0.283	0.21	0.009	0.082	4.043	0.374	0.046	2.693
F	3	74433	2	2.145	0.091	0.018	2.227	6.188	0.465	0.064	4.92
E	2	132056	3	0.137	0.091	0.037	0.137	6.325	0.557	0.1	5.057
D	1	158541	9	0.228	0.219	0.046	0.137	6.553	0.776	0.146	5.194
E	3	198084	2	0.913	0.119	0.429	1.652	7.466	0.894	0.575	6.846
E	4	264112	1	0.758	0.064	0.246	1.314	8.224	0.958	0.821	8.16
D	**2**	317083	3	0.292	0.228	0.128	0.155	8.516	**1.187**	0.949	8.315
E	5	330140	1	0.365	0.009	0.082	0.666	8.881	1.196	1.031	8.981
D	3	475624	2	0.675	0.785	1.041	0.776	9.556	1.981	2.072	9.757
D	4	634165	1	0.748	0.739	1.123	1.068	10.305	2.72	3.195	10.825
D	5	792707	1	0.758	0.666	1.059	0.986	11.062	3.386	4.253	11.811
D	6	951248	1	0.283	0.511	0.675	0.438	11.345	3.897	4.929	12.249
D	7	1109789	1	0.164	0.329	0.438	0.155	11.51	4.226	5.367	12.404
D	8	1268331	1	0.027	0.11	0.173	0.037	11.537	4.336	5.54	12.441

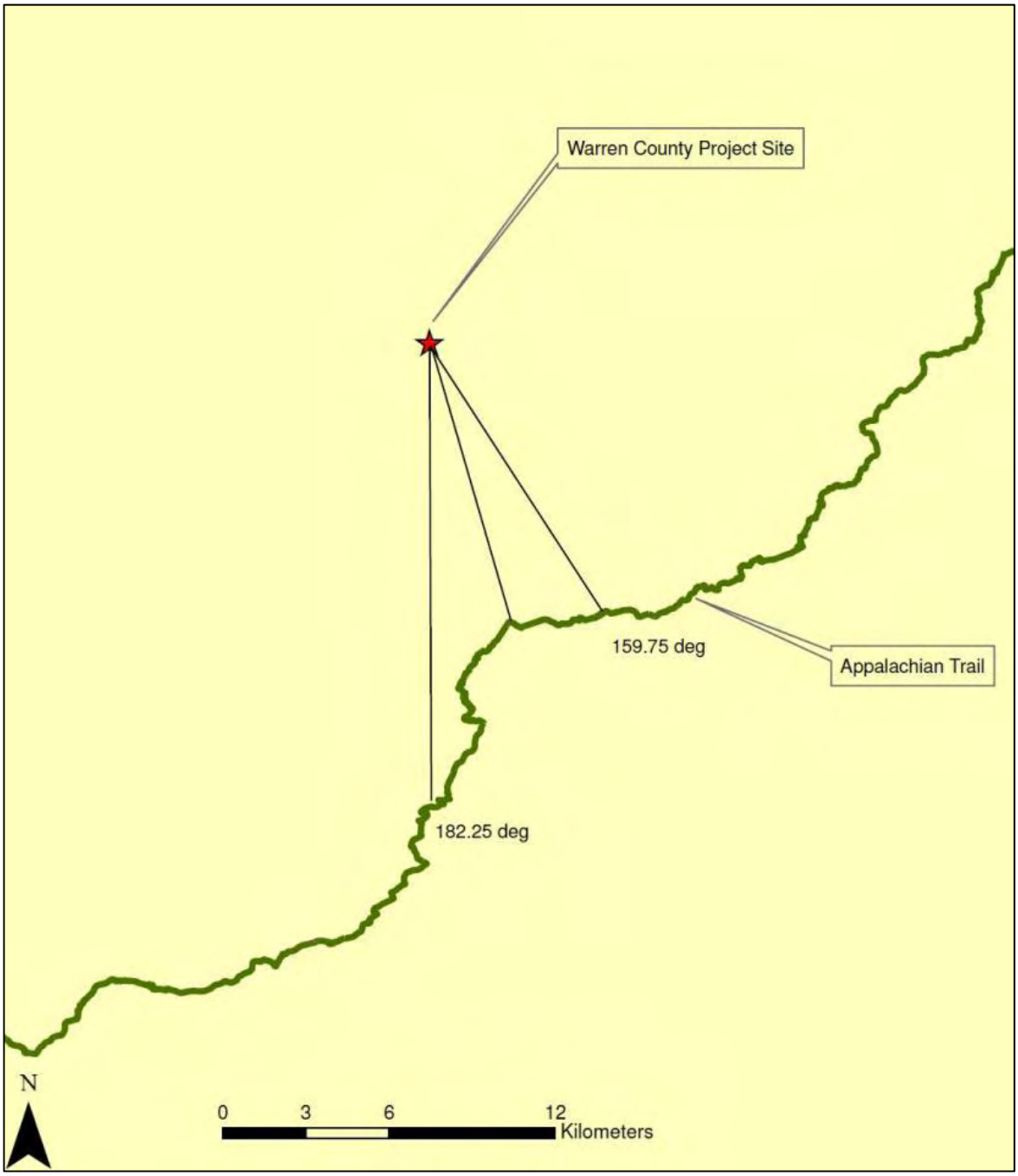
Notes: m/s = meters/second m^3/s = cubic meters/second

Table 9-6 VISCREEN Model Results

Operation Case	Background	Distance (km)	Plume Perceptibility (ΔE)			Plume Contrast (C_p)		
			VISCREEN[1]		Criteria	VISCREEN[1]		Criteria
			Theta 10	Theta 140		Theta 10	Theta 140	
Start-up /Shutdown	Sky	10.3	1.188	0.414	2.00	0.008	-0.009[(2)]	0.05
	Terrain	17.0	1.469	0.183	2.00	0.011	0.004	0.05
Normal	Sky	10.3	1.112	0.332	2.00	0.012	-0.010[(2)]	0.05
	Terrain	17.0	1.888	0.228	2.00	0.014	0.005	0.05

1. VISCREEN results are provided for the two VISCREEN default worst-case theta angles. The two theta angles represent the sun being in front of the observer (theta = 10 degrees) or behind the observer (theta = 140 degrees).
2. A negative C_p means the plume has a darker contrast than the background sky.

Figure 9-2 Appalachian Trail Relative to the Warren County Site and the Sector



10.0 $PM_{2.5}$ Modeling Analysis

10.1 Overview of Modeling Approach

EPA has recently provided national guidance for modeling compliance with the $PM_{2.5}$ NAAQS[8]. Until recently, EPA accepted modeled compliance with the PM_{10} NAAQS as a surrogate for indicating compliance with the $PM_{2.5}$ NAAQS, in accordance with a 1997 Office of Air Quality Planning and Standards memo that provided EPA guidance on this matter. However, recent rulings by EPA have resulted in revised guidance for permit applicants to attempt to address the issue of modeled compliance with the $PM_{2.5}$ NAAQS directly, even in the absence of EPA modeling guidance.

In response to a request from VA DEQ, AECOM has conducted a NAAQS compliance analysis for $PM_{2.5}$ according to guidance issued by EPA OAQPS Director Mr. Steve Page. One key issue with demonstrating compliance with the $PM_{2.5}$ NAAQS is that background concentrations typically constitute a large fraction of the NAAQS, and are often much higher than the Project impacts. EPA modeling guidance in 40 CFR Part 51, Appendix W addresses situations where background concentrations are not dominant, and this guidance has not been updated to address the $PM_{2.5}$ NAAQS cases in which background concentrations are dominant.

Another modeling issue that is unresolved for compliance with the $PM_{2.5}$ NAAQS is that EPA has not yet defined the Significant Impact Levels (SILs) that are applicable for $PM_{2.5}$. These SILs are proposed in the September 21, 2007 Federal Register (72 FR 54139-54140), which also establishes the legal basis for SILs to determine whether a proposed source will cause or contribute to a NAAQS violation. Therefore, AECOM adopted the option with the overall lowest EPA-proposed values for both PSD Class I and II modeling in order to define the extent to which receptors need to be placed for cumulative modeling. Support for the use of the lowest proposed SIL comes from Mr. Dan DeRoeck of EPA, who indicated (2009) that the final EPA rule would have a SIL within the range of the proposed options. Therefore, the use of the lowest proposed SILs is a conservative approach. The SILs that were used for the permit application are the EPA-proposed Option 3 values of 1.2 $\mu g/m^3$ and 0.3 $\mu g/m^3$ for the daily and annual averages for PSD Class II modeling, and 0.07 $\mu g/m^3$ and 0.06 $\mu g/m^3$ for daily and annual averages for PSD Class I modeling. Cumulative NAAQS modeling was limited to those receptors for which the lowest proposed SILs were exceeded for modeling of the Project impacts alone.

10.2 $PM_{2.5}$ Significant Impact Level Analysis

10.2.1 $PM_{2.5}$ Significant Impact Analysis for Class II Areas

As mentioned earlier, AECOM conducted the SIL analysis using the overall lowest EPA-proposed values for the PSD Class II modeling. The SILs that were used for the permit application are the EPA-proposed Option 3 values of 1.2 $\mu g/m^3$ and 0.3 $\mu g/m^3$ for the daily and annual averages for PSD Class II modeling.

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[8] http://www.epa.gov/ttn/scram/Official%20Signed%20Modeling%20Proc%20for%20Demo%20Compli%20w%20PM2.5.pdf

The same methodology as used for the SIL analysis of the criteria pollutants was used for the SIL analysis of $PM_{2.5}$. The same set of meteorological data as used for the other criteria pollutants SIL analysis was used for the $PM_{2.5}$ modeling analysis. However, the Class II receptor grid was extended farther than the other criteria pollutants grid to capture maximum extents.

The Class II grid consisted of receptors spaced 25 m apart along the fence line. A spacing of 50 m was used for the receptors beyond the fence line and extending out to 1 km from the fence line. Beyond 1 km from the fence line, a spacing of 100 m was used up to 2.5 km from the plant. Between 2.5 and 5 km, a spacing of 500 m was used. Between 5 and 10 km, a spacing of 1,000 m was used. Beyond 10 km, a spacing of 2000 m was used extending out to 25 km from the plant. No receptors within the Shenandoah National Park were included in the Class II analysis. Receptors with 1000-m spacing were placed at the boundary of the Class I Area extending out to 25 km. The receptor grid used in the modeling analysis was based on NAD 83 datum and in zone 17. The extent of this grid was sufficient to capture maximum impacts in the Class II area analysis. Figure 10-1 shows the far-field Cartesian receptor grid considered in the modeling analysis.

As discussed in the protocol, the receptor grid was refined around the receptor with the maximum concentration, if it was outside the 50-meter spacing grid. This was done to ascertain that none of the receptors with impacts potentially exceeding the SILs were missed. The maximum impacts for $PM_{2.5}$ annual were found to be within the 50-meter spacing and therefore, no refined receptors were added to the Cartesian grid. A 2-km by 2-km grid with 50-meter spacing receptors centered on the receptor with maximum impact for each year was added to the above-mentioned discrete Cartesian grid for the $PM_{2.5}$ 24-hour averaging period. Figure 10-2 shows the refined receptor grid considered for the $PM_{2.5}$ 24-hour modeling analysis.

The same methodology, as discussed for other criteria pollutants in Section 6, was followed for the startup/shutdown modeling analysis for $PM_{2.5}$ as well. The same receptor grid (20-km Cartesian grid) as used for other criteria pollutants was used for the $PM_{2.5}$ startup/shutdown analysis.

Receptor height scales at each receptor location (used in AERMOD) were developed by AERMAP (version 09040), the terrain preprocessor for AERMOD. AERMAP was run using the 1/3 arc second (~10 m resolution) National Elevation Data (NED) for the proposed project location which was downloaded from the United States Geological Services (USGS) website (http://seamless.usgs.gov/index.php). As per the AERMAP User's Guide (USEPA, 2004), the domain was sufficiently large enough to accommodate all the significant nodes such that all terrain features that exceed a 10% elevation slope from any given receptor were considered. Figure 10-3 shows the modeling domain to demonstrate this. The full report generated by AERMAP is provided in Appendix F and is included with the modeling files on the DVD.

Figure 10-1 Far Field Receptor Grid for $PM_{2.5}$ Modeling Analysis

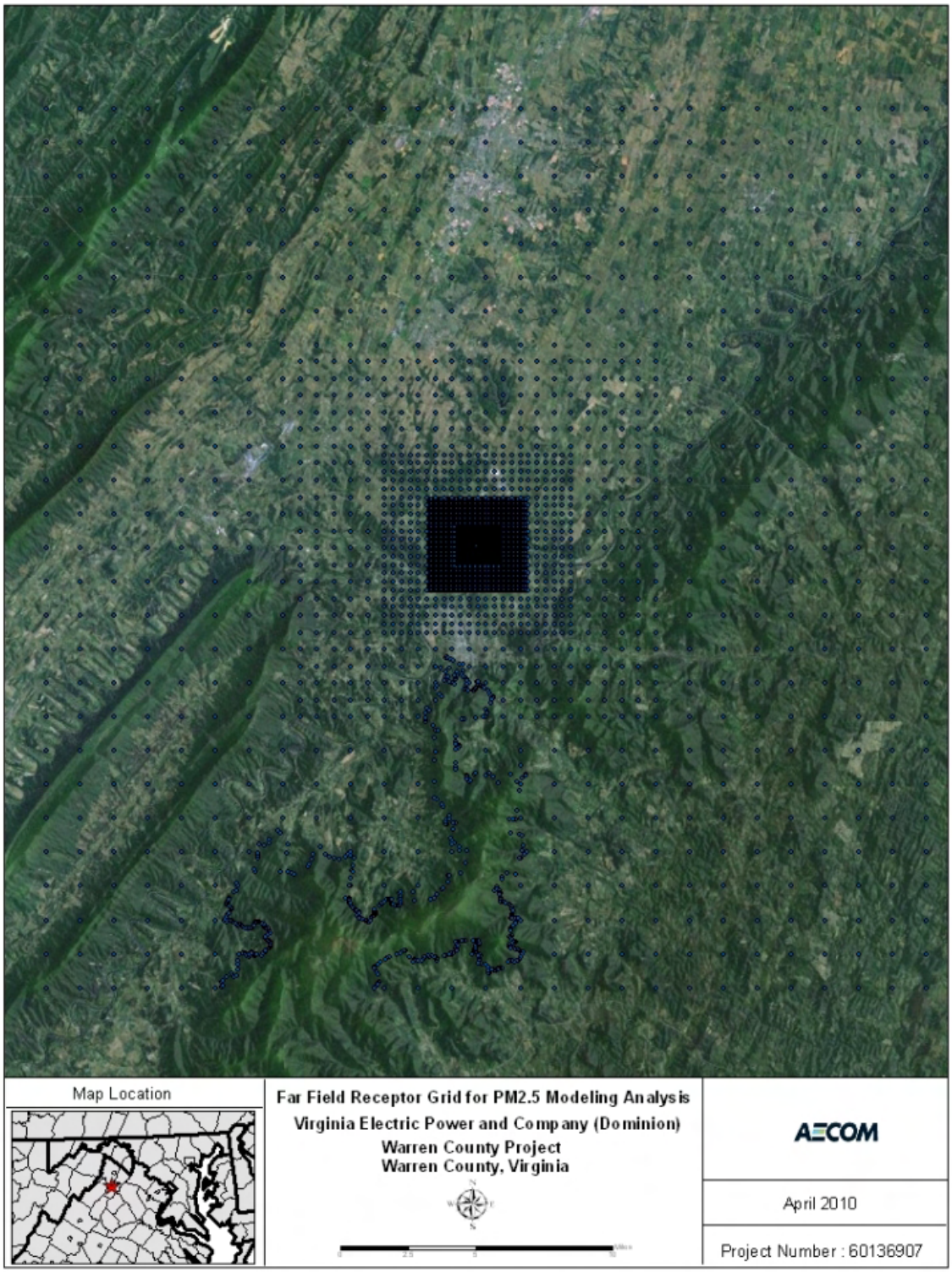


Figure 10-2 Refined Receptor Grid for $PM_{2.5}$ 24-hour SIL AERMOD Modeling Analysis

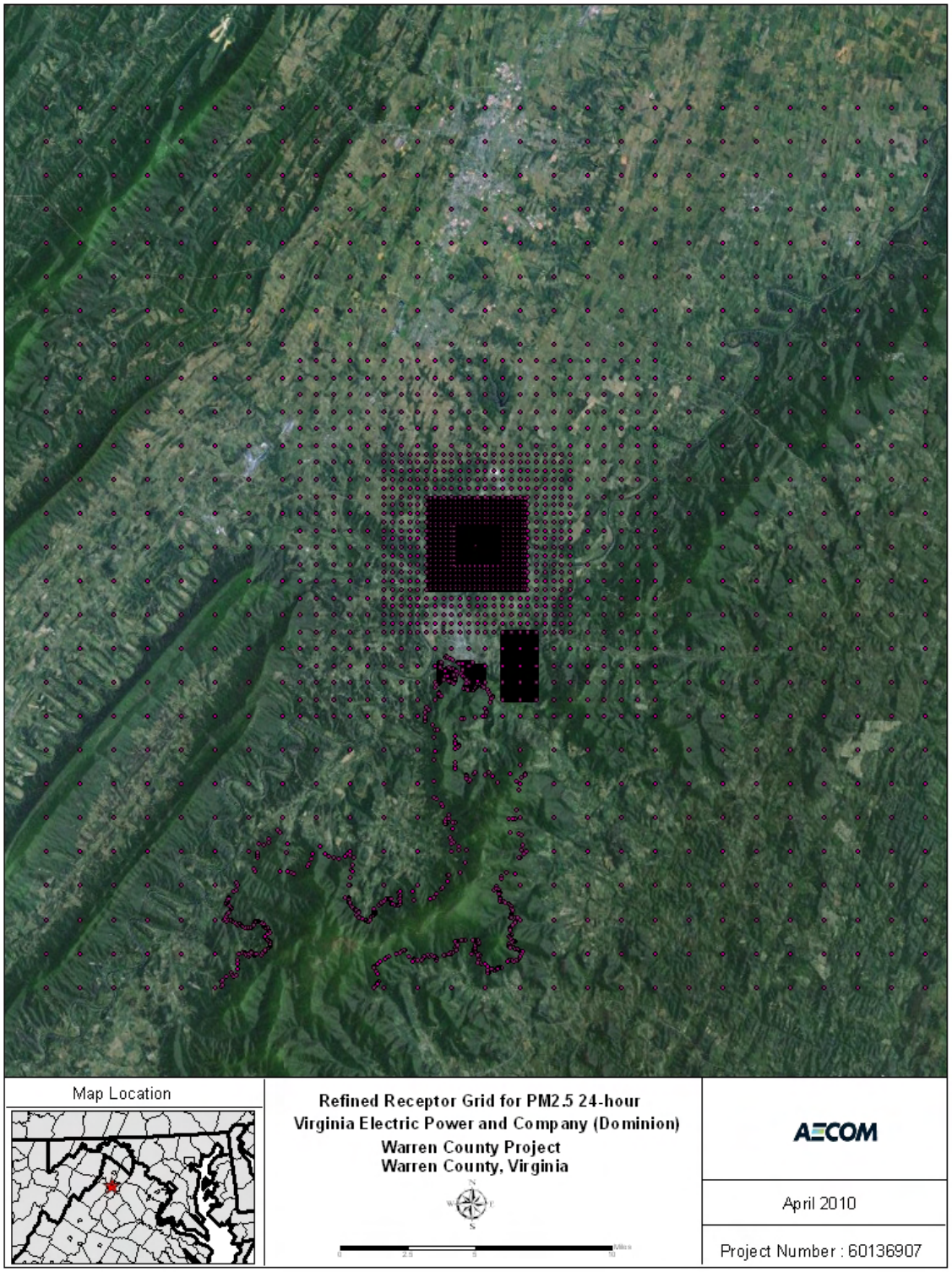
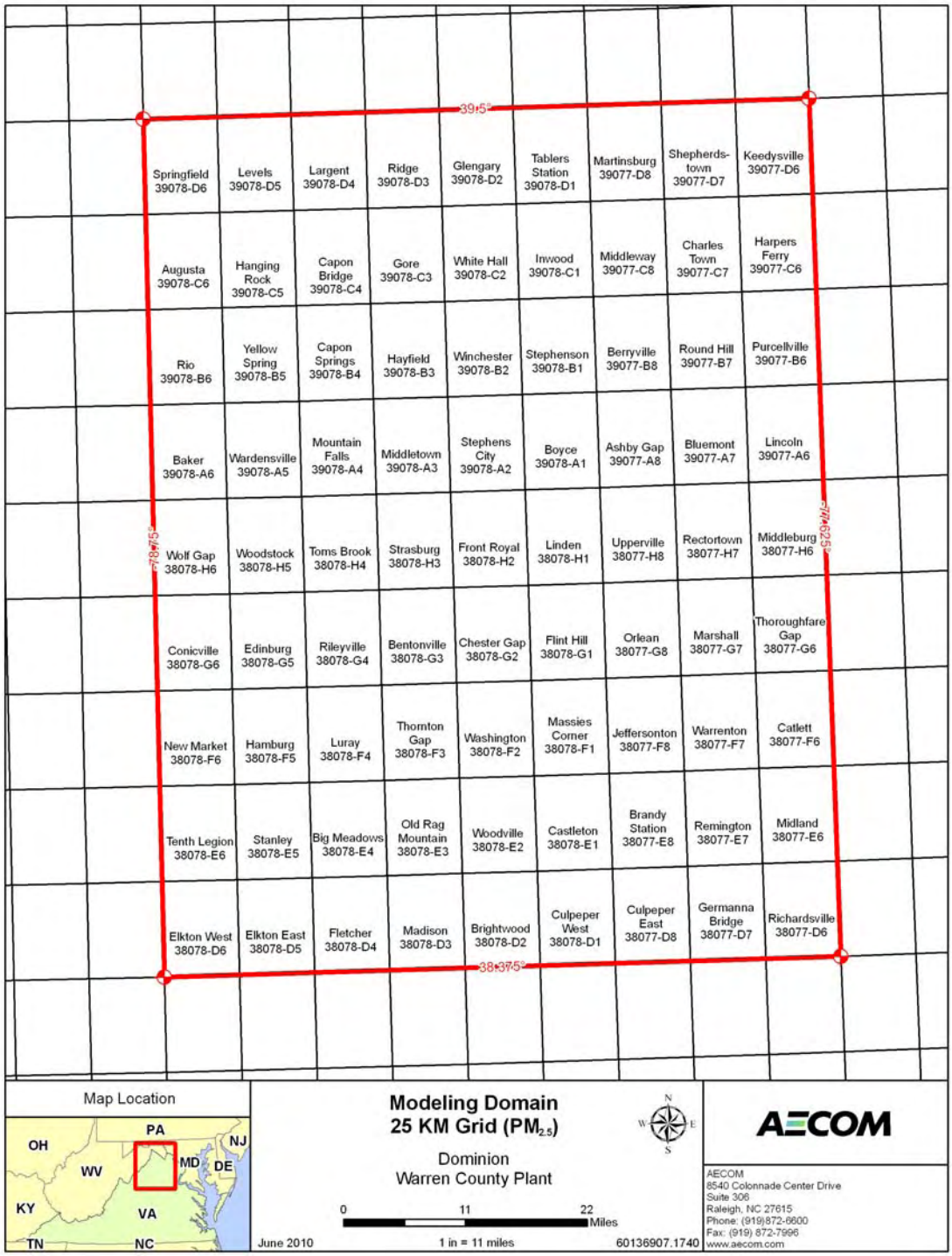


Figure 10-3 Domain Used in the Modeling Analysis for $PM_{2.5}$



The results of the $PM_{2.5}$ modeling for comparison to the lowest proposed Class II SILs are presented in Tables 10-1 for the normal operations and 10-2 for startup/shutdown operations. Table 10-1 presents the maximum ground-level concentrations at each of the four operating loads for the Cartesian receptor grid for $PM_{2.5}$ 24-hour and annual averaging periods. The maximum ground level concentrations for $PM_{2.5}$ 24-hour correspond to the refined receptor grid – refined receptors around the maximum impact and the regular Cartesian grid. Each of the four load groups include emissions from the three combined-cycle combustion turbines at the respective load, inlet turbine chillers, auxiliary boiler, diesel-fired fire-water pump, diesel-fired emergency generator, and fuel gas heater. Table 10-2 presents the maximum ground level concentrations for $PM_{2.5}$ 24-hour for either a cold or a warm startup and the remaining time in the averaging period with the normal operation emissions at 100% with duct firing load. Table 10-2 also presents the maximum ground level concentrations for $PM_{2.5}$ annual that were modeled based on the combination of annualized startup/shutdown emissions and the annualized normal operation emissions across all the operating loads.

Table 10-1 PSD Class II $PM_{2.5}$ Impacts of Proposed Project Sources Only – Normal Operations

Pollutant	Averaging Period	Total Maximum Impact ($\mu g/m^3$)	Lowest Proposed SIL ($\mu g/m^3$)	Cumulative Modeling Needed? (Yes/No)
100% Load with Duct Firing				
$PM_{2.5}$	24-Hr	6.74	1.2	Yes
	Annual	0.31	0.3	Yes
100% Load				
$PM_{2.5}$	24-Hr	4.87	1.2	Yes
	Annual	0.31	0.3	Yes
75% Load				
$PM_{2.5}$	24-Hr	4.22	1.2	Yes
	Annual	0.36	0.3	Yes
60% Load				
$PM_{2.5}$	24-Hr	4.10	1.2	Yes
	Annual	0.41	0.3	Yes

Table 10-2 PSD Class II $PM_{2.5}$ Impacts of Proposed Project Sources Only – Startup/Shutdown Operations

Pollutant	Averaging Period	Total Maximum Impact ($\mu g/m^3$)	Lowest Proposed SIL ($\mu g/m^3$)	Cumulative Modeling Needed? (Yes/No)
$PM_{2.5}$	24-Hr	3.91	1.2	Yes
	Annual	0.36	0.3	Yes

The results indicate that the proposed project impacts' trigger a cumulative modeling analysis when compared to the lowest proposed SILs. For a background inventory, $PM_{2.5}$ emissions were used for the sources for which a $PM_{2.5}$ emission rate was provided, otherwise, the PM_{10} emissions were used, even though $PM_{2.5}$ emissions are a subset of PM_{10} emissions.

The results of the multi-source modeling analysis are discussed in Section 10.3.

10.2.2 $PM_{2.5}$ Significant Impact Analysis for Shenandoah National Park

As mentioned earlier, AECOM conducted the analysis using the overall lowest EPA-proposed values for the PSD Class I modeling. The SILs that were used for the permit application are the EPA-proposed Option 3 values of 0.07 $\mu g/m^3$ and 0.06 $\mu g/m^3$ for the daily and annual averages for PSD Class I modeling.

The same methodology used for the Class I SIL analysis of the criteria pollutants was used for the Class I SIL analysis of $PM_{2.5}$. The same set of meteorological data, receptors, and model options as used for the other criteria pollutants Class I SIL analysis was used for the Class I $PM_{2.5}$ modeling analysis.

The results of the $PM_{2.5}$ modeling for comparison to the lowest proposed Class I SILs are presented in Table 10-3. The table presents the maximum ground level concentrations at each of the four operating loads for $PM_{2.5}$ 24-hour and annual. Each of the four load groups include emissions from the three combined-cycle combustion turbines at the respective load, inlet turbine chillers, auxiliary boiler, diesel-fired fire-water pump, diesel-fired emergency generator and fuel gas heater.

The results indicate that the proposed project impacts trigger a Class I cumulative modeling analysis when compared to the lowest proposed SILs. For a background inventory, $PM_{2.5}$ emissions were used for the sources for which a $PM_{2.5}$ emission rate was provided, otherwise the PM_{10} emissions were used, even though $PM_{2.5}$ emissions are a subset of PM_{10} emissions.

The results of the multi-source modeling analysis are discussed in Section 10.3.

Table 10-3 PSD Class I $PM_{2.5}$ Impacts of Proposed Project Sources Only

Pollutant	Averaging Period	Total Maximum Impact ($\mu g/m^3$)	Lowest Proposed SIL ($\mu g/m^3$)	Cumulative Modeling Needed? (Yes/No)
100% Load with Duct Firing				
$PM_{2.5}$	24-Hr	5.55	0.07	Yes
	Annual	0.18	0.06	Yes
100% Load				
$PM_{2.5}$	24-Hr	3.99	0.07	Yes
	Annual	0.18	0.06	Yes
75% Load				
$PM_{2.5}$	24-Hr	3.41	0.07	Yes
	Annual	0.19	0.06	Yes
60% Load				
$PM_{2.5}$	24-Hr	3.09	0.07	Yes
	Annual	0.21	0.06	Yes

10.3 $PM_{2.5}$ Cumulative Impact Analysis

10.3.1 $PM_{2.5}$ Cumulative Impact Analysis for Class II Areas

The Tier 1 (conservative) approach utilized for any cumulative modeling of $PM_{2.5}$ adopted a, design value from the nearby representative $PM_{2.5}$ monitor at Luray Caverns Airport. This concentration was conservatively assumed to apply for <u>each</u> modeled day at all receptors.

The modeled impacts for $PM_{2.5}$ NAAQS compliance are based on the highest modeled concentration averaged over the 5 years, consistent with EPA OAQPS guidance posted at www.epa.gov/scram001. The modeled $PM_{2.5}$ annual concentration of interest was taken to be the maximum modeled 5-year average annual concentration over all modeled receptors. Similarly, the modeled $PM_{2.5}$ 24-hour concentration of interest was taken to be the maximum modeled 5-year 24-hour concentration over all modeled receptors.

In addition to the modeled project impacts plus a design value, impacts were included from other nearby emission sources with emissions high enough and close enough to likely cause a significant concentration gradient within an area referred to as the “Significant Impact Area”, or SIA. This area is defined for Class II areas as the farthest distance from the source (up to 50 km) for which a peak modeled impact at a receptor exceeds the Class II SIL for either daily or annual averages.

The same methodology for developing the nearby source inventory as discussed in Sections 7.5 through 7.9 was also applied to the multi-source modeling analysis for $PM_{2.5}$. The SIA radius and the corresponding screening radius for $PM_{2.5}$ (24-hour and annual averaging period) is provided below:

- $PM_{2.5}$ 24 Hour: 26.5 km 76.5 km
- $PM_{2.5}$ annual : 1.0 km 51.0 km

A summary of the nearby sources that were modeled is provided in Appendix G. The complete emission source inventory is provided on the DVD (along with the other modeling files) in Appendix F.

As previously mentioned, the AERMOD model was used in the multi-source modeling analyses. After a thorough evaluation of the nearby emission sources for multi-source modeling analysis, the application of the model was determined. The methodology is discussed below.

For NAAQS compliance, AECOM used AERMOD to model the other nearby NAAQS emission sources along with the proposed project's sources in simple and complex terrain. The objective for using this model is to capture cumulative impacts within the SIA.

For the proposed project, the same stack parameters and emission rates (see Section 6 for details) as used for the SIL modeling was used for the multi-source modeling analyses. The cumulative receptor grid consisted of the receptors that exceeded the $PM_{2.5}$ 24-hr SIL for each load and each year. Any duplicate receptors were deleted from the combined receptor grid. The same set of meteorological data from the SIL analysis was used for this analysis.

The highest 5-year average annual and 24-hour modeled concentrations were retrieved and added to the corresponding design value. The design values for $PM_{2.5}$ from the nearby representative $PM_{2.5}$ monitor at Luray Caverns airport is provided in Table 6-15. These final values were then compared to the NAAQS to determine compliance. Figure 6-9 shows the location of the ambient background monitor for $PM_{2.5}$ considered in the analysis.

The results of the multi-source modeling analysis are presented below.

10.3.2 Summary of Class II Area $PM_{2.5}$ NAAQS Analysis

A complete summary of the NAAQS analysis is presented in Table 10-4. "Model Concentration" refers to the combined impacts from the proposed project sources and the NAAQS background sources. The model concentrations were determined by finding the highest 5-year average annual and 24-hour modeled concentration from the AERMOD model. The appropriate design value was added to the model concentration to obtain the final concentration, which are listed in the "Total Concentration" column, for comparison to the NAAQS. The table below presents the model concentration over the four operating loads and five years of meteorological data.

As shown in Table 10-4, the predicted impacts for $PM_{2.5}$ 24-hour in the NAAQS cumulative impact analysis will be less than the NAAQS. The results of the NAAQS modeling analysis show that the project will not cause or contribute to a NAAQS violation. Hence, the proposed project is deemed to be in compliance with the applicable NAAQS standards.

Table 10-4 Summary of Class II Area $PM_{2.5}$ NAAQS Analysis

Pollutant	Averaging Period	Model Concentration ($\mu g/m^3$)	Design Value ($\mu g/m^3$) (1)	Total Concentration ($\mu g/m^3$)	NAAQS ($\mu g/m^3$)	Complies (Y/N)?
$PM_{2.5}$	24-hour	4.38 (4.23)(2)	28.00	32.38	35.00	Y
$PM_{2.5}$	Annual	0.48 (0.38)(2)	11.70	12.18	15.00	Y

(1) Design value from taken from Virginia Ambient Air Monitor 2008 Report Data
(2) Dominion project source contribution shown in parentheses.

10.3.3 $PM_{2.5}$ Cumulative Impact Analysis for Shenandoah National Park

Similar to the Class II $PM_{2.5}$ cumulative impact assessment, the Tier 1 (conservative) approach for any cumulative modeling of $PM_{2.5}$ adopted a conservatively high 98th percentile daily monitored background concentration, averaged over the period of 2006-2008, from the nearby representative $PM_{2.5}$ monitor at Luray Caverns airport. This concentration was conservatively assumed to apply for each modeled day at all receptors.

The modeled impact for $PM_{2.5}$ NAAQS was calculated in similar manner as discussed above for the Class II $PM_{2.5}$ modeling. The modeled impacts for $PM_{2.5}$ NAAQS compliance are based on the highest modeled concentration averaged over the 5 years, consistent with EPA OAQPS guidance posted at www.epa.gov/scram001. The modeled $PM_{2.5}$ annual concentration of interest was taken to be the maximum modeled 5-year average annual concentration over all modeled receptors. Similarly, the modeled $PM_{2.5}$ 24-hour concentration of interest was taken to be the maximum modeled 5-year 24-hour concentration over all modeled receptors.

In addition to the modeled project impacts plus a regional background value, impacts were included from other nearby NAAQS sources with emissions high enough and close enough to likely cause a significant concentration gradient within 50 km of Shenandoah NP. Consistent with the cumulative modeling conducted for the Class I area discussed in Section 8, only nearby emissions sources within 50-km of Shenandoah were considered for inclusion into the cumulative modeling analysis.

A summary of the nearby NAAQS sources that were modeled is provided in Appendix G. The complete nearby source emission inventory is provided on the DVD (along with the other modeling files) in Appendix F.

As previously mentioned, the AERMOD model was used in the multi-source modeling analyses. After a thorough evaluation of the nearby emissions sources for multi-source modeling analysis, the application of the model was determined. The methodology is discussed below.

For NAAQS compliance, AECOM used AERMOD to model other nearby NAAQS sources along with the proposed project's sources in simple and complex terrain. The objective for using this model is to capture cumulative impacts within the SIA. The model options, meteorology, source data used for the SIL modeling was also used for the multi-source modeling analysis.

The highest 5-year average annual and 24-hour modeled concentrations were retrieved and added to the corresponding design value. The design value for $PM_{2.5}$ from the nearby representative $PM_{2.5}$ monitor at Luray Caverns Airport is provided in Table 6-15. These final values were then compared to

the NAAQS to determine compliance. Figure 6-9 shows the location of the ambient background monitor for $PM_{2.5}$ considered in the analysis.

The results of the multi-source modeling analysis are presented below.

10.3.4 Summary of NAAQS Analysis for Shenandoah National Park

A complete summary of the NAAQS analysis for Shenandoah National Park is presented in Table 10-5. "Model Concentration" refers to the combined impacts from the proposed project sources and the NAAQS background sources. The model concentrations were determined by finding the 5-year average highest annual and 24-hour modeled concentrations from the AERMOD model. The appropriate design value was then added to the model concentration to obtain the final concentration, which are listed in the "Total Concentration" column, for comparison to the NAAQS. The table below presents the model concentration over the four operating loads and five years of meteorological data.

As shown in Table 10-5, the predicted impacts for 24-hour and annual $PM_{2.5}$ in the NAAQS cumulative impact analysis will be less than the NAAQS. The result of the NAAQS modeling analysis shows that the project will not cause or contribute to a NAAQS violation. Hence, the proposed project is deemed to be in compliance with the applicable NAAQS standards.

Table 10-5 Summary of NAAQS Analysis for Shenandoah National Park

Pollutant	Averaging Period	Model Concentration ($\mu g/m^3$)	Design Value ($\mu g/m^3$) (1)	Total Concentration ($\mu g/m^3$)	NAAQS ($\mu g/m^3$)	Complies (Y/N)?
$PM_{2.5}$	24-hour	3.74 (3.72)(2)	28.0	31.74	35.00	Y
$PM_{2.5}$	Annual	0.13 (0.11)(2)	11.7	11.83	15.00	Y

(1) Design value from taken from Virginia Ambient Air Monitor 2008 Report Data.
(2) Dominion project source contribution shown in parentheses.

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Appendix A

Application Forms

Appendix B

Vendor Information and Emission Calculations

Table B-9 Emergency Generator Emissions

Emission Source:	Emergency Generator
Source Type:	Diesel Generator
Engine Power (bhp):	2,193
Heat Input (mmBtu/hr):	16.91
Maximum Fuel Usage (gal/hr)	119.9
Number of Units:	1
Fuel Oil Heating Value (BTU/gal)	141,000
Sulfur Content of Fuel (wt. %):	0.0015
Operating Hours per Year:	500

Compound	Emission Factor	Emission Factor	Emission Rate	
			Hourly (d)	Annual (e)
	(g/kW-hr)	(g/hp-hr)	(lb/hr)	(ton/year)
Nitrogen Oxides (a)	6.4	4.8	23.08	5.77
Carbon Monoxide (a)	3.5	2.6	12.62	3.16
TOC (a)	6.4	4.8	23.08	5.77
Sulfur Oxides (b)	0.0015	0.0015	2.54E-02	6.34E-03
PM (a)	0.20	0.15	0.72	0.18
PM-10 (c)	0.40	0.30	1.44	0.36

Notes:

(a) Emission factors (g/kW-hr) for NOx, CO, TOC and PM are based on the NSPS Subpart IIII limits for Stationary Compression Ignition Internal Combustion Engines (reference 40 CFR 89.112 Table 1).

(b) lb/MMBtu based on fuel sulfur.

(c) Since AP-42 does not provide an emission factor for PM-10, the TSP emission rate was multiplied by a factor of 2 to conservatively estimate the contribution of condensables.

(d) Hourly Emission Rate (lb/hr) = Emission Factor (g/hp-hr) * Engine Power (hp) * (1 lb / 453.6 g)

(e) Annual Emission Rate (ton/yr) = Hourly Emission Rate (lb/hr) * Hour of Operation Per Year (hr/yr) / (2,000 lb/ton)

Stack Parameters (Each)

Stack Height	115.0	ft
Stack Diameter	1.23	ft
Stack Exit Velocity	135	ft/sec
Exhaust Flow	9,669	ACFM
Exhaust Temp	987	F

Appendix F

Air Dispersion Modeling Files

DIRECTORIES/SUB-DIRECTORIES PROVIDED ON DVD-ROM

DIRECTORIES/SUB-DIRECTORIES PROVIDED ON DVD-ROM

AERMET

No changes from prior submittal.

AERSURFACE

No changes from prior submittal.

Class I

AERMOD Project	modeling files for project alone runs (descriptions below)
AERMOD Cumulative	modeling files for cumulative runs (descriptions below)
AERMOD Deposition	modeling files used Level II nitrogen deposition analysis
AERMAP	No changes from prior submittal.
PLUVUE	No changes from prior submittal.
Soil and Veg	No changes from prior submittal.

File naming Convention for AERMOD Project:

AERMOD Project

Dominion_x_y_z.t

where,

x = Year (1988, 1989, 1990, 1991, 1992)

y = Pollutant ID
- NO_x – Nitrogen Oxides
- PM_{10} – Particulate Mater (< 10 microns)
- $PM_{2.5}$ – Particulate Mater (< 2.5 microns)
- SO_2 – Sulfur Dioxide

z = Averaging Period
- ANN – Annual
- 24HR – 24-hour averaging period

t = file type (dta=input, lst=output)

ANNy-b-x.plt

where,

y = Pollutant ID
- NO_x – Nitrogen Oxides

SO_2 – Sulfur Dioxide

b = Load
- 100DF – 100% load with duct firing
- 100LD – 100% load without duct firing
- 75LD – 75% load without duct firing
- 50LD – 50% load without duct firing

x = Year (1988, 1989, 1990, 1991, 1992)

.plt = AERMOD plot file

aermod.exe — AERMOD executable (version 09292)

File naming Convention for AERMOD Cumulative:
The convention is the same for all folders.

AERMOD Cumulative

Dominion_x_y_z.t

where,

x = Year (1988, 1989, 1990, 1991, 1992)

y = Pollutant ID
- NO_x – Nitrogen Oxides
- PM_{10} – Particulate Mater (< 10 microns)
- $PM_{2.5}$ – Particulate Mater (< 2.5 microns)

z = Averaging Period
- ANN – Annual
- 24HR – 24-hour averaging period

t = file type (dta=input, lst=output)

zy-x.plt

where,

z = Averaging Period
- ANN – Annual
- 24H1 – 24-hour averaging period; high first high result

y = Pollutant ID
- $PM_{2.5}$ – Particulate Mater (< 2.5 microns)

x = Year (1988, 1989, 1990, 1991, 1992)

	.plt = AERMOD plot file
aermod.exe	AERMOD executable (version 09292)

File naming Convention for AERMOD Deposition:
The convention is the same for all folders.

AERMOD Deposition

Dominion_1988_NOx_1HR.t	
	where,
	t = file type (dta=input, lst=output)
NO2_88.pos	AERMOD post file
aermod.exe	AERMOD executable (version 09292)

File naming Convention for AERMAP Modeling:

AERMAP

No changes from prior submittal.

Class II

AERMAP – 20km grid	No changes from prior submittal.
AERMAP – 25km grid	No changes from prior submittal.
AERMOD	AERMOD modeling files (See file descriptions below)

File naming Convention for AERMAP Modeling:

AERMAP for SIL Analysis

No changes from prior submittal.

File naming Convention for AERMOD Modeling:

SIL Analysis

Dominion_Arpt_3x3x1_x_y_z.t

where, Dominion_Arpt_3x3x1= AERMOD modeling files for SIL Analysis

x = Year (1988, 1989, 1990, 1991, 1992)

y = Pollutant ID
- NO_x – Nitrogen Oxides
- PM_{10} – Particulate Mater (< 10 microns)
- CO – Carbon Monoxide

z = Averaging Period
- ANN – Annual
- 24HR – 24-hour averaging period
- 8HR – 8-hour averaging period
- 1HR – 1-hour averaging period

t = file type (dta=input, lst=output)

Dominion_Arpt_3x3x1_b_c_x_y_z.GRF

where, Dominion_Arpt_3x3x1= AERMOD modeling files for SIL Analysis

b = Load
- 100DF – 100% load with duct firing
- 100LD – 100% load without duct firing
- 75LD – 75% load without duct firing

60LD – 60% load without duct firing

c = results type
FIRST – high first high
SECOND – high second high

x = Year (1988, 1989, 1990, 1991, 1992)

y = Pollutant ID
NO_x – Nitrogen Oxides
PM_{10} – Particulate Mater (< 10 microns)
CO – Carbon Monoxide

z = Averaging Period
ANN – Annual
24HR – 24-hour averaging period
8HR – 8-hour averaging period
1HR – 1-hour averaging period

.GRF = AERMOD plot file

SIL Analysis – $PM_{2.5}$

Dominion_Arpt_3x3x1_x_y_z.t

where, Dominion_Arpt_3x3x1= AERMOD modeling files for SIL Analysis

x = Year (1988, 1989, 1990, 1991, 1992)

y = Pollutant ID
$PM_{2.5}$ – Particulate Mater (< 2.5 microns)

z = Averaging Period
AN – Annual
24 – 24-hour averaging period

t = file type (dta=input, lst=output)

Dominion_Arpt_3x3x1_c _b _x_y_z.GRF

where, Dominion_Arpt_3x3x1= AERMOD modeling files for SIL Analysis

b = Load
100DF – 100% load with duct firing
100LD – 100% load without duct firing

75LD – 75% load without duct firing
60LD – 60% load without duct firing

c = results type
FIRST – high first high for the 24 hr results

x = Year (1988, 1989, 1990, 1991, 1992)

y = Pollutant ID
$PM_{2.5}$ – Particulate Mater (< 2.5 microns)

z = Averaging Period
AN – Annual
24 – 24-hour averaging period

.GRF = AERMOD plot file

SIL Analysis – $PM_{2.5}$ – Refined $PM_{2.5}$

Dominion_Arpt_3x3x1_x_y_z.t

where, Dominion_Arpt_3x3x1= AERMOD modeling files for SIL Analysis

x = Year (1988, 1989, 1990, 1991, 1992)

y = Pollutant ID
$PM_{2.5}$ – Particulate Mater (< 2.5 microns)

z = Averaging Period
24 – 24-hour averaging period

t = file type (dta=input, lst=output)

Dominion_Arpt_3x3x1_c _b _x_y_z.GRF

where, Dominion_Arpt_3x3x1= AERMOD modeling files for SIL Analysis

b = Load
100DF – 100% load with duct firing
100LD – 100% load without duct firing
75LD – 75% load without duct firing
60LD – 60% load without duct firing

c = results type

FIRST – high first high for the 24 hr results

x = Year (1988, 1989, 1990, 1991, 1992)

y = Pollutant ID
$PM_{2.5}$ – Particulate Mater (< 2.5 microns)

z = Averaging Period
24 – 24-hour averaging period

.GRF = AERMOD plot file

SIL Analysis – Refined PM_{10} Grid

Dominion_Arpt_3x3x1_ x_y_z.t

where, Dominion_Arpt_3x3x1= AERMOD modeling files for SIL Analysis

x = Year (1988, 1989, 1990, 1991, 1992)

y = Pollutant ID
PM_{10} – Particulate Mater (< 10 microns)

z = Averaging Period
24H – 24-hour averaging period

t = file type (dta=input, lst=output)

Dominion_Arpt_3x3x1_b_c_x_y_z.GRF

where, Dominion_Arpt_3x3x1= AERMOD modeling files for SIL Analysis

b = Load
100DF – 100% load with duct firing
100LD – 100% load without duct firing
75LD – 75% load without duct firing
60LD – 60% load without duct firing

c = results type
FIRST – high first high results
SECOND – high second high results

x = Year (1988, 1989, 1990, 1991, 1992)

y = Pollutant ID
PM_{10} – Particulate Mater (< 10 microns)

z = Averaging Period
24H – 24-hour averaging period

.GRF = AERMOD plot file

CIA - PM_{10}

Dominion_Dominion_Arpt_3x3x1_Cumulative_x_y_z.t

where, Dominion_Arpt_3x3x1_Cumulative = AERMOD modeling files for CIA Analysis

x = Year (1988, 1989, 1990, 1991, 1992)

y = Pollutant ID
PM_{10} – Particulate Mater (< 10 microns)

z = Averaging Period
24H – 24-hour averaging period

t = file type (dta=input, lst=output)

CIA - $PM_{2.5}$ – 24-hour

The naming convention is the same for the culp folder.

Dominion_ Arpt_3x3x1_Cumulative_x_y_z.t

where, Dominion_Arpt_3x3x1_Cumulative = AERMOD modeling files for CIA Analysis

x = Year (1988-92)

y = Pollutant ID
$PM_{2.5}$ – Particulate Mater (< 2.5 microns)

z = Averaging Period
24H – 24-hour averaging period

t = file type (dta=input, lst=output)

Dominion_Arpt_3x3x1_Cumulative_b_x_y_z.GRF

where, Dominion_Arpt_3x3x1_Cumulative = AERMOD modeling files for CIA Analysis

b = Source Group and Load
- ALLDF – 100% load with duct firing
- ALL100 – 100% load without duct firing
- ALL75 – 75% load without duct firing
- ALL60 – 60% load without duct firing

x = Year (1988, 1989, 1990, 1991, 1992)

y = Pollutant ID
- $PM_{2.5}$ – Particulate Mater (< 10 microns)

z = Averaging Period
- 24H – 24-hour averaging period

.GRF = AERMOD plot file

CIA - $PM_{2.5}$ – Annual

The naming convention is the same for the culp folder.

Dominion_ Arpt_3x3x1_Cumulative_x_y_z.t

where, Dominion_Arpt_3x3x1_Cumulative = AERMOD modeling files for CIA Analysis

x = Year (1988-92)

y = Pollutant ID
- $PM_{2.5}$ – Particulate Mater (< 2.5 microns)

z = Averaging Period
- ANN – annual averaging period

t = file type (dta=input, lst=output)

Dominion_Arpt_3x3x1_Cumulative_b_x_y_z.GRF

where, Dominion_Arpt_3x3x1_Cumulative = AERMOD modeling files for CIA Analysis

b = Source Group and Load
- ALLDF – 100% load with duct firing
- ALL100 – 100% load without duct firing

ALL75 – 75% load without duct firing
ALL60 – 60% load without duct firing

x = Year (1988, 1989, 1990, 1991, 1992)

y = Pollutant ID
$PM_{2.5}$ – Particulate Mater (< 10 microns)

z = Averaging Period
ANN – annual averaging period

.GRF = AERMOD plot file

Vegetation Analysis

Dominion_Arpt_3x3x1_Veg_x_y_z.t

where, Dominion_Arpt_3x3x1_Veg = AERMOD modeling files for Vegetation Analysis

x = Year (1988, 1989, 1990, 1991, 1992)

y = Pollutant ID
NO_x – Nitrogen Oxides
PM_{10} – Particulate Mater (< 10 microns)
CO – Carbon Monoxide

z = Averaging Period
ANN – Annual
1M – Month
24HR – 24-hour averaging period
4HR – 4-hour averaging period
1HR – 1-hour averaging period

t = file type (dta=input, lst=output)

Toxics Analysis

Dominion_Arpt_3x3x1_Toxic_x_y_z.t

where, Dominion_Arpt_3x3x1_Toxic = AERMOD modeling files for Toxic Analysis

x = Year (1988, 1989, 1990, 1991, 1992)

y = Pollutant ID
- ACRL – Acrolein
- FRML – Formaldehyde
- CADM – Cadmium
- CHRM – Chromium
- NCKL – Nickel

z = Averaging Period
- ANN – Annual
- 1HR – 1-hour averaging period

t = file type (dta=input, lst=output)

aermod.exe — Located in Class I folder

Startup/Shutdown (SUSD) Analysis

Dominion_y_SU_x_y_z.t

where, Dominion_Arpt_3x3x1_SUSD = AERMOD modeling files for SUSD Analysis

x = Year (1988, 1989, 1990, 1991, 1992)

y = Pollutant ID
- NO_x – Nitrogen Oxides
- PM_{10} – Particulate Mater (< 10 microns)
- $PM_{2.5}$ – Particulate Mater (< 2.5 microns)
- CO – Carbon Monoxide

z = Averaging Period
- ANN or AN – Annual
- 24HR or 24 or 24H – 24-hour averaging period
- 8HR – 8-hour averaging period
- 1HR – 1-hour averaging period

t = file type (dta=input, lst=output)

Stack Identification:

Warren County Combined-Cycle Project Sources

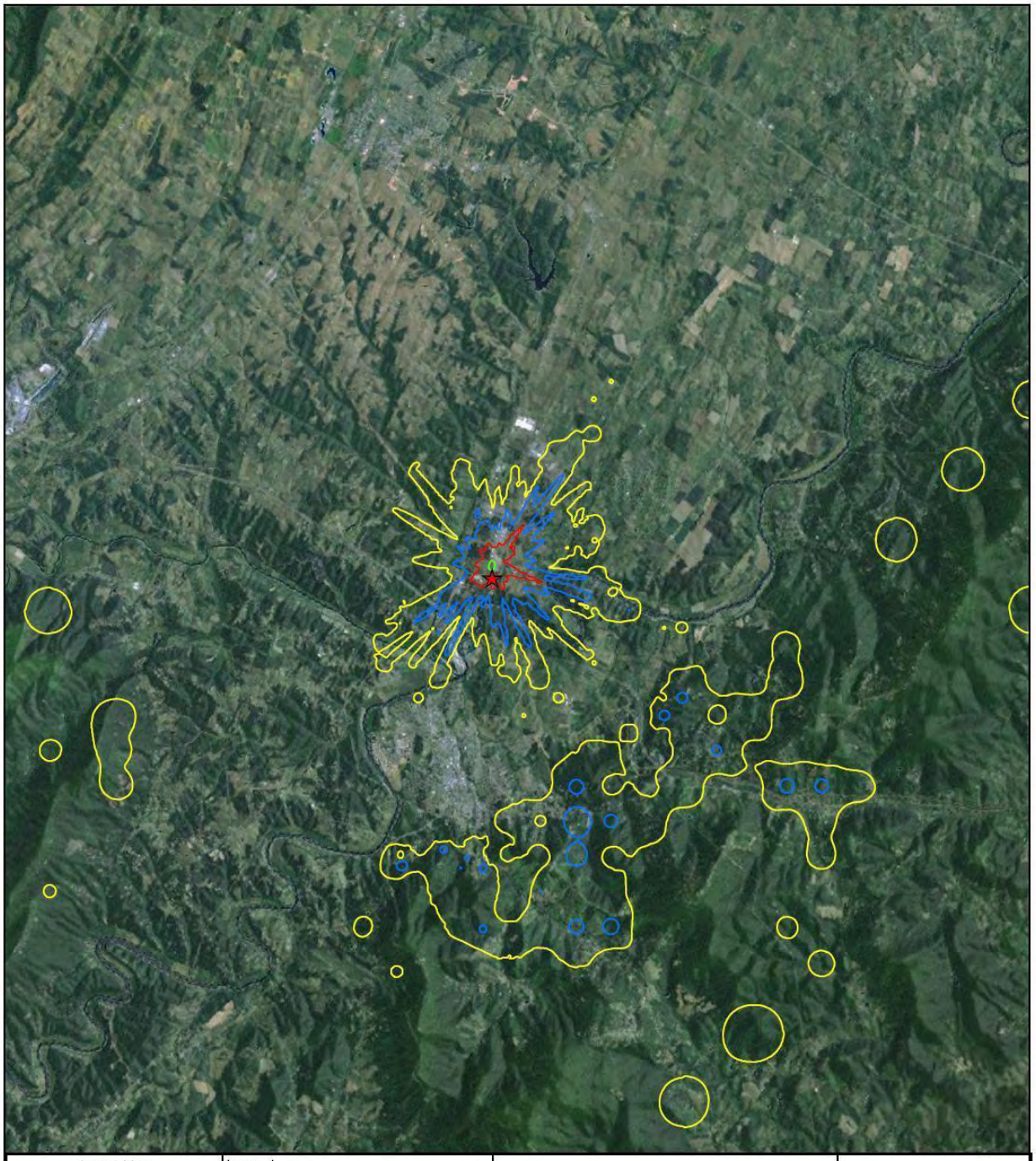
CCNG1A – 100% Load with Duct Firing
CCNG2A – 100% Load with Duct Firing
CCNG3A – 100% Load with Duct Firing
CCNG1B – 100% Load
CCNG2B – 100% Load
CCNG3B – 100% Load
CCNG1C – 75% Load
CCNG2C – 75% Load
CCNG3C – 75% Load
CCNG1D – 60% Load
CCNG2D – 60% Load
CCNG3D – 60% Load
AUX_BLR – Auxiliary Boiler
DSL_GEN – Diesel Engine Generator
FWP – Diesel Fire Pump
FGH – Fuel Gas Heater
CHLR1_U1 – Chiller 1 - Unit 1
CHLR1_U2 – Chiller 1 - Unit 2
CHLR1_U3 – Chiller 1 - Unit 3
CHLR1_U4 – Chiller 1 - Unit 4
CHLR1_U5 – Chiller 1 - Unit 5
CHLR1_U6 – Chiller 1 - Unit 6
CHLR2_U1 – Chiller 2 - Unit 1
CHLR2_U2 – Chiller 2 - Unit 2
CHLR2_U3 – Chiller 2 - Unit 3
CHLR2_U4 – Chiller 2 - Unit 4
CHLR2_U5 – Chiller 2 - Unit 5
CHLR2_U6 – Chiller 2 - Unit 6
CHLR3_U1 – Chiller 3 - Unit 1
CHLR3_U2 – Chiller 3 - Unit 2
CHLR3_U3 – Chiller 3 - Unit 3
CHLR3_U4 – Chiller 3 - Unit 4
CHLR3_U5 – Chiller 3 - Unit 5
CHLR3_U6 – Chiller 3 - Unit 6

Nearby Sources for the Cumulative Impact Assessment

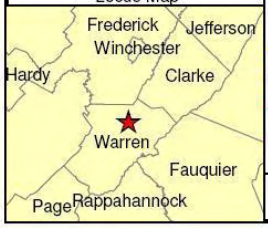
Please refer to the background source emission inventory included on the DVD (also included as Appendix G) for a list of the modeled background sources included in the cumulative impact analysis (CIA) for both PM_{10} and $PM_{2.5}$

Appendix H

Air Quality Impacts-Contour Map



Locus Map



Legend

Proposed Warren County Site

10 $\mu g/m^3$ Contour

25 $\mu g/m^3$ Contour

50 $\mu g/m^3$ Contour

100 $\mu g/m^3$ Contour

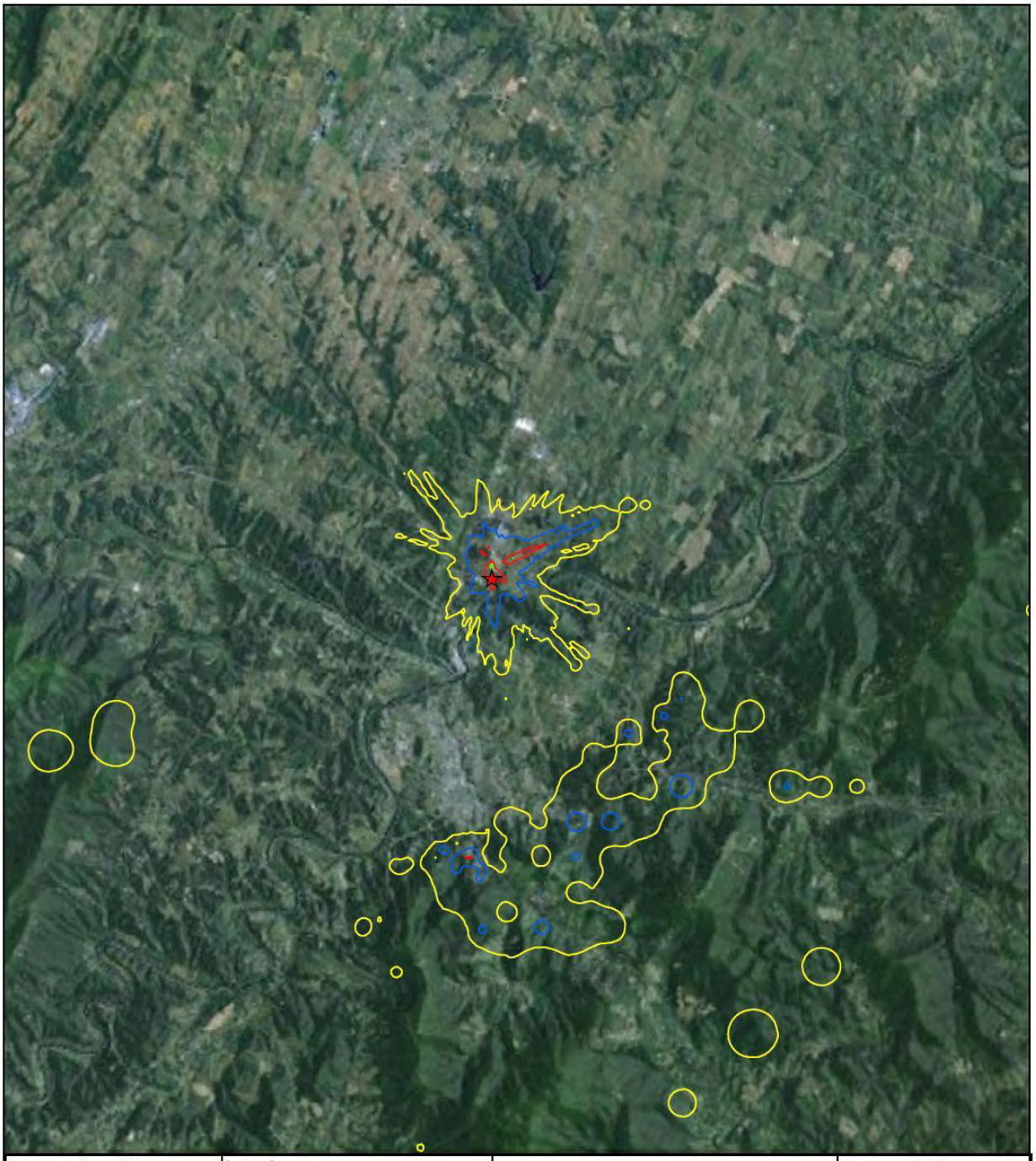
Scale 0 2.5 5 10 15 Kilometers

Contour Map
CO 1-Hour

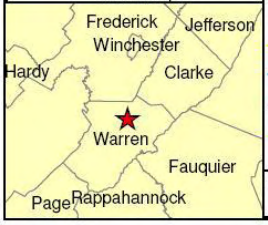
Dominion
Warren County Plant

Dominion

AECOM



Locus Map



Legend

- Proposed Warren County Site
- 2.5 $\mu g/m^3$ Contour
- 5 $\mu g/m^3$ Contour
- 10 $\mu g/m^3$ Contour
- 15 $\mu g/m^3$ Contour

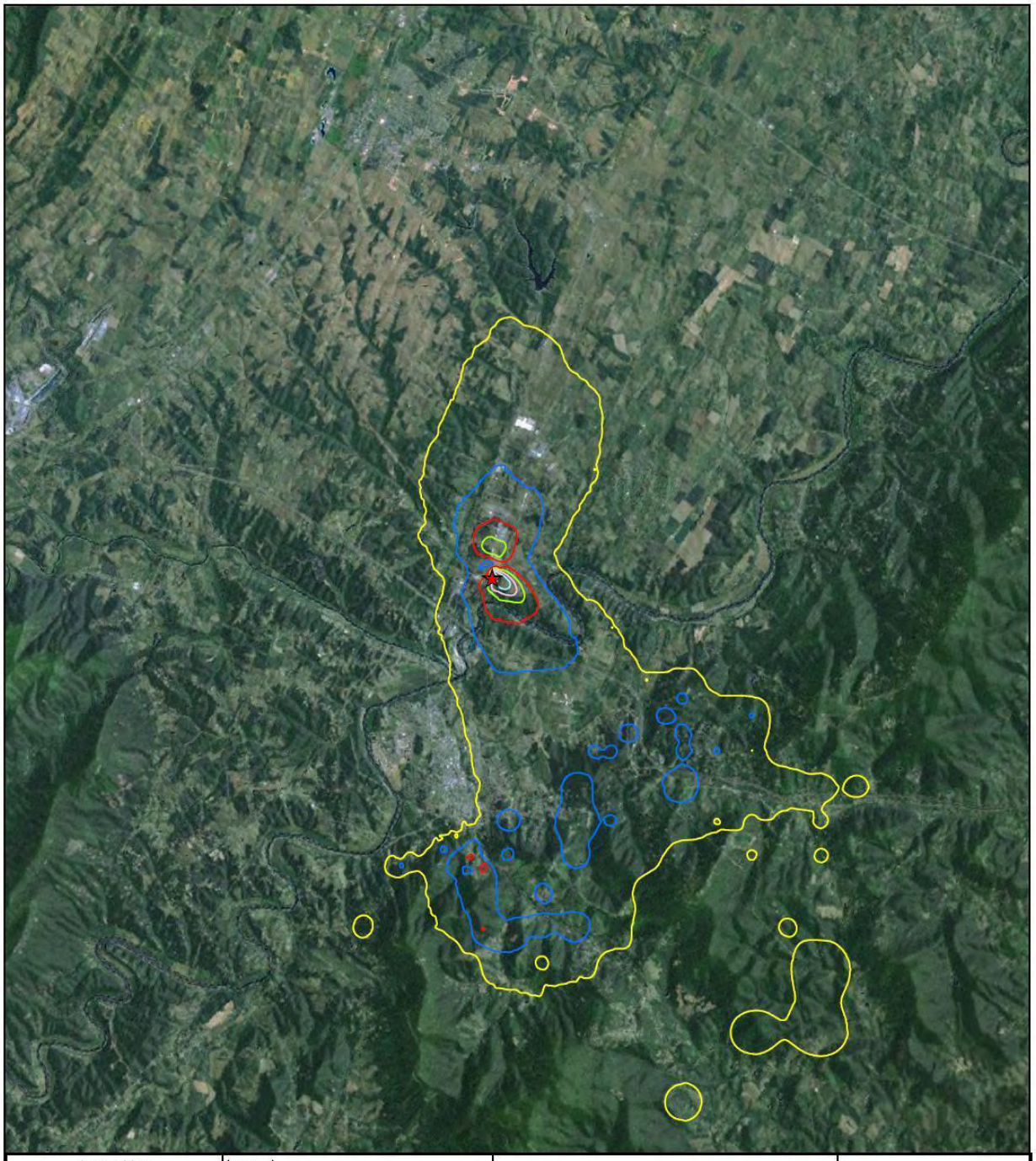
Scale 0 2.5 5 10 15 Kilometers

Contour Map
CO 8-Hour

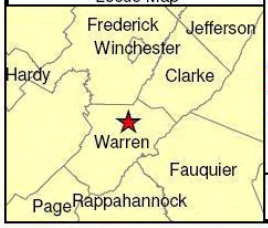
Dominion
Warren County Plant

Dominion

AECOM



Locus Map



Legend

- Proposed Warren County Site
- 0.05 $\mu g/m^3$ Contour
- 0.1 $\mu g/m^3$ Contour
- 0.2 $\mu g/m^3$ Contour
- 0.3 $\mu g/m^3$ Contour
- 0.4 $\mu g/m^3$ Contour
- 0.5 $\mu g/m^3$ Contour

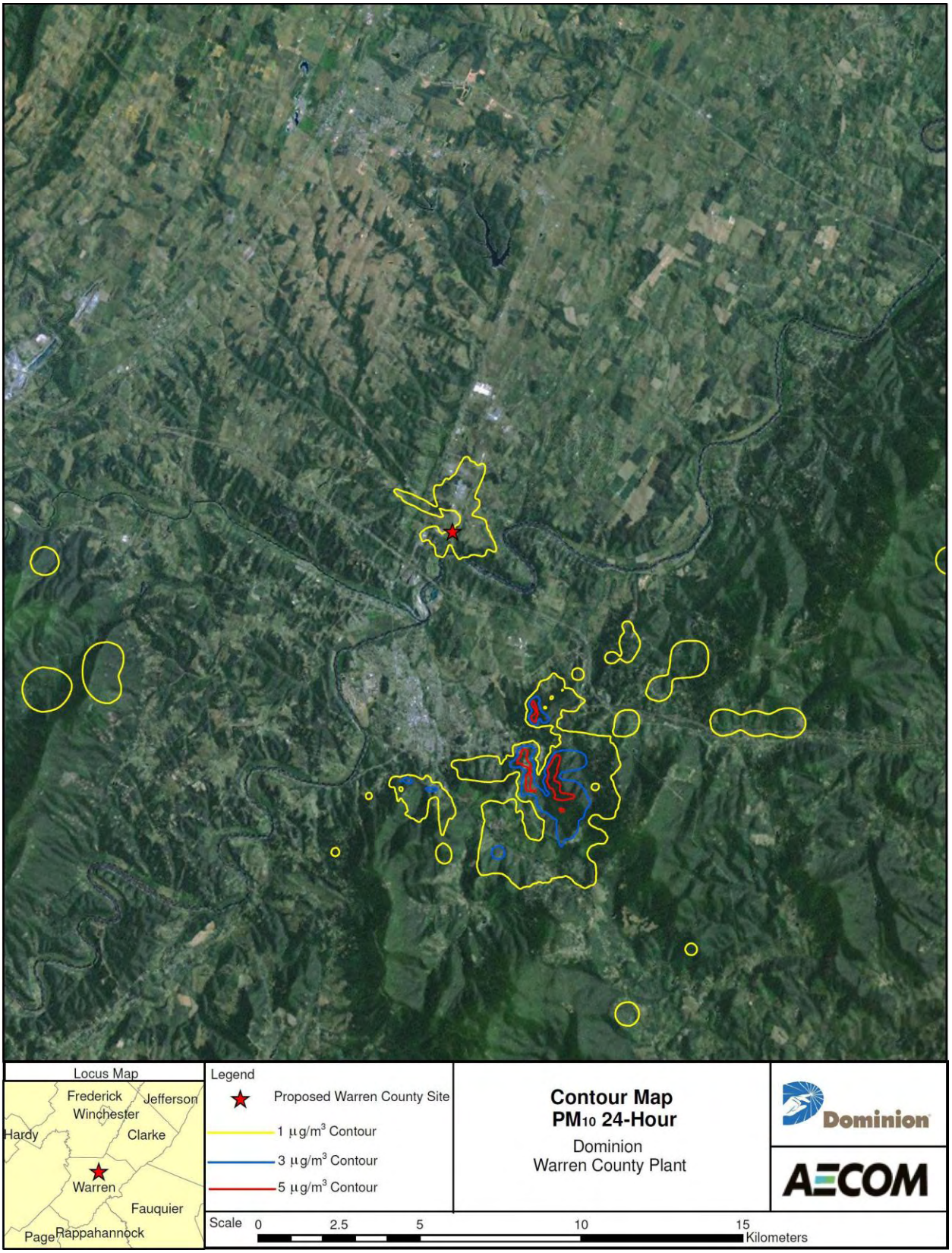
Scale 0 2.5 5 10 15 Kilometers

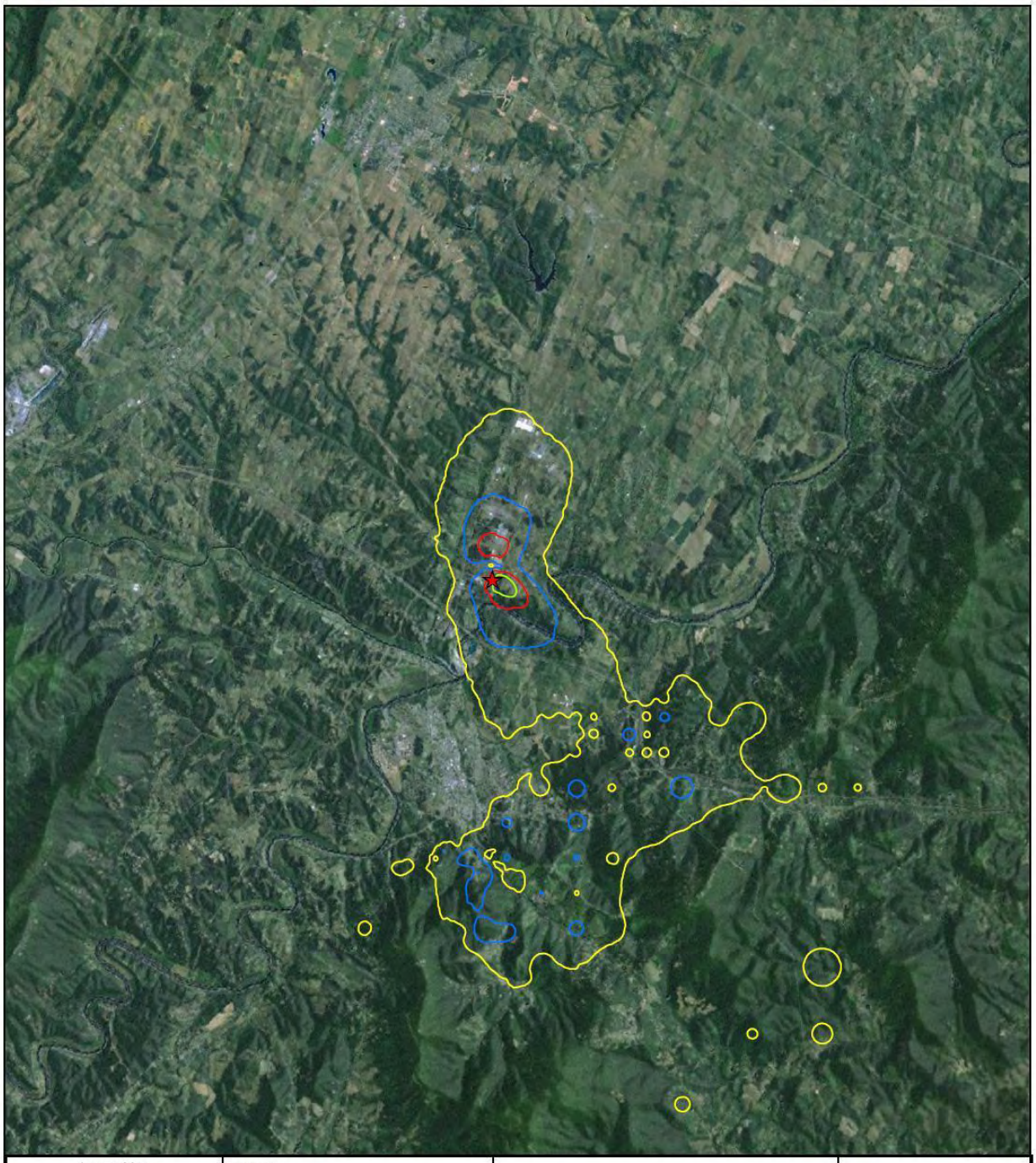
Contour Map
NO_2 Annual

Dominion
Warren County Plant

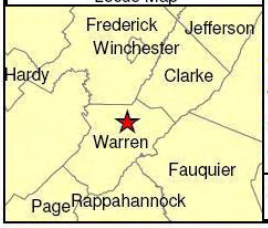
Dominion

AECOM


Locus Map
Frederick
Jefferson
Winchester
Hardy
Clarke
Warren
Fauquier
Page
Rappahannock
Legend
Proposed Warren County Site
1 µg/m³ Contour
3 µg/m³ Contour
5 µg/m³ Contour
Scale 0 2.5 5 10 15 Kilometers
Contour Map
PM10 24-Hour
Dominion
Warren County Plant
Dominion
AECOM



Locus Map



Legend

- Proposed Warren County Site
- 0.05 $\mu g/m^3$ Contour
- 0.1 $\mu g/m^3$ Contour
- 0.2 $\mu g/m^3$ Contour
- 0.3 $\mu g/m^3$ Contour

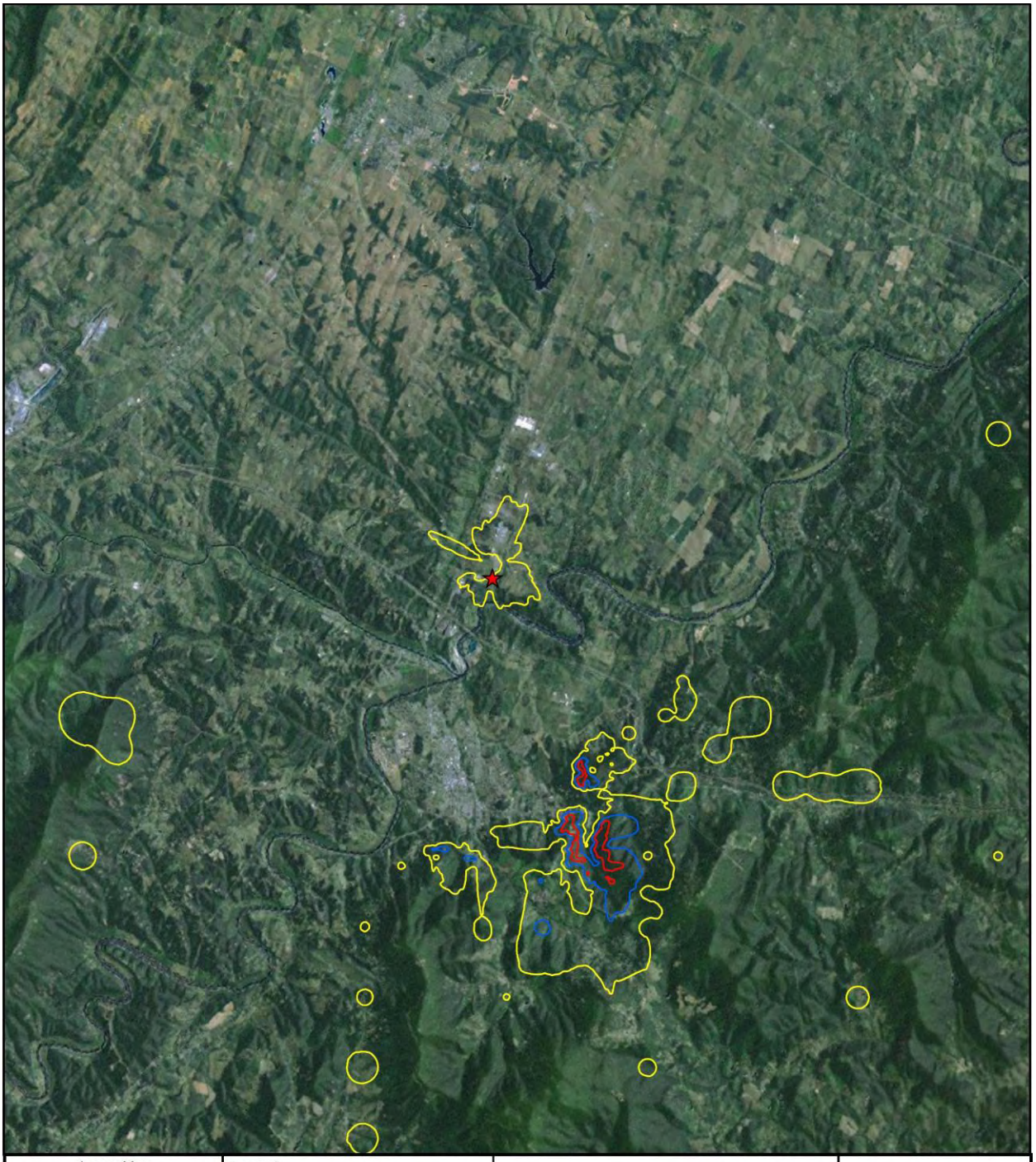
Scale 0 2.5 5 10 15 Kilometers

Contour Map
PM_{10} Annual

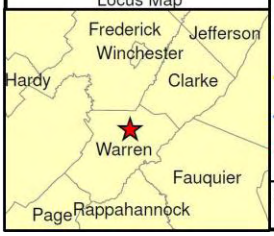
Dominion
Warren County Plant

Dominion

AECOM



Locus Map



Legend

Proposed Warren County Site

1 $\mu g/m^3$ Contour

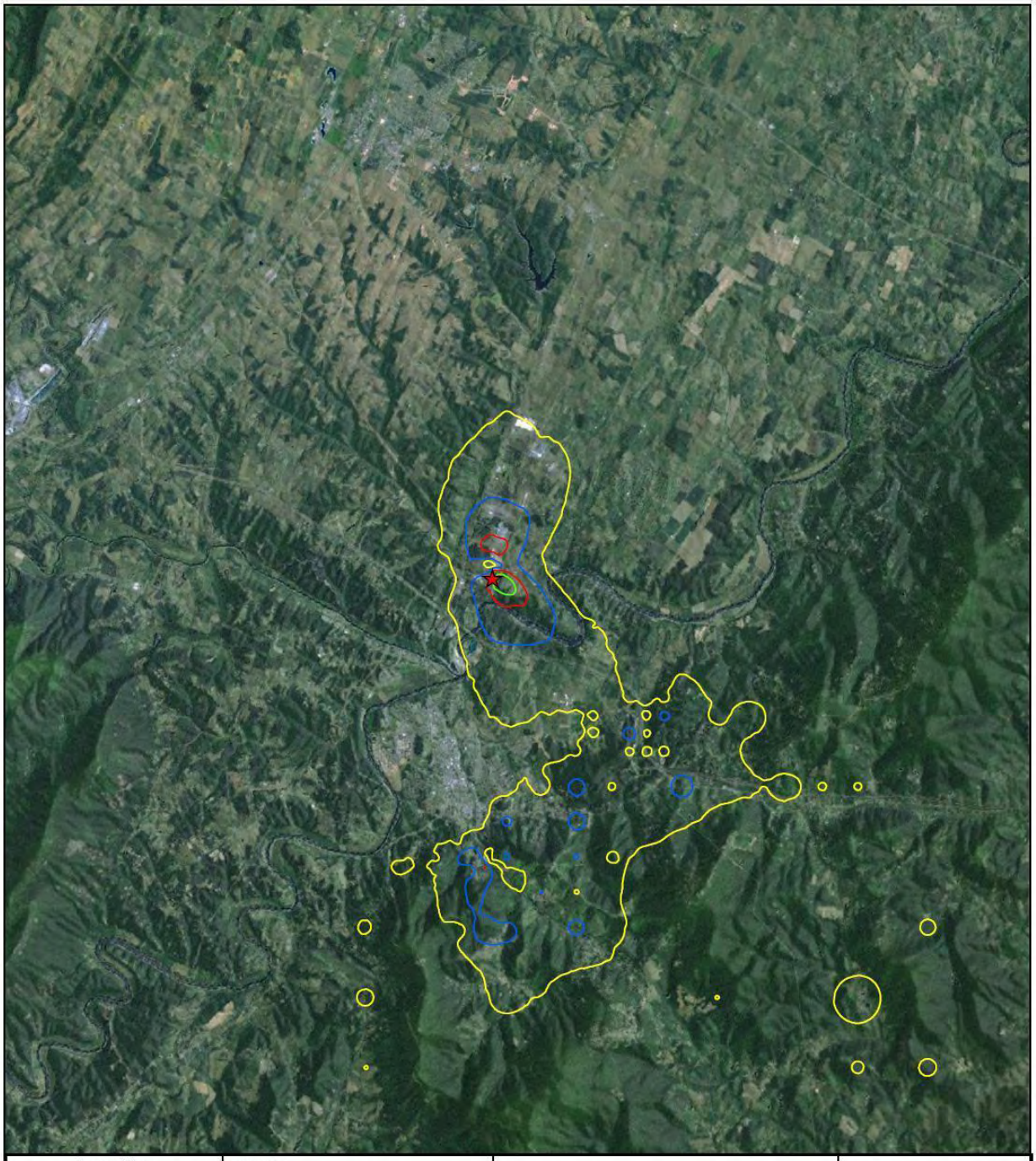
3 $\mu g/m^3$ Contour

5 $\mu g/m^3$ Contour

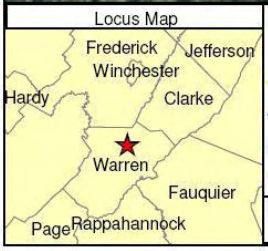
Contour Map
$PM_{2.5}$ 24-Hour

Dominion
Warren County Plant

Scale 0 2.5 5 10 15 Kilometers



Locus Map



Legend

- Proposed Warren County Site
- 0.05 $\mu g/m^3$ Contour
- 0.1 $\mu g/m^3$ Contour
- 0.2 $\mu g/m^3$ Contour
- 0.3 $\mu g/m^3$ Contour

Scale 0 2.5 5 10 15 Kilometers

Contour Map
$PM_{2.5}$ Annual

Dominion
Warren County Plant

Dominion

AECOM

Appendix I

Technical Papers Describing a Refined Plume Visibility Approach

Effects of Plume Subtended Angle on Visibility Impairment over a Class I Area

Paper No. 277

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ABSTRACT

Permitting of a major proposed new or modified emissions source near a Class I area may require the assessment of potential plume visibility impairment within the Class I area. In certain cases, this assessment requires refined analysis using the PLUVUE II plume visibility model. This model calculates the contrast and color difference of a plume against its background, for input date, and time of day, and hourly weather conditions.

In December 2000, the Federal Land Managers' Air Quality Related Values Work Group (FLAG) adopted fixed visibility guideline thresholds for contrast (0.02) and color difference (1.0), based on narrow plumes to which the human eye is most sensitive. However, the original 1978 research showed that contrast perception threshold increased significantly as a function of the angle subtended by the plume (wider, more diffuse plumes are harder to see). Recent research by Willard Richards, *et al.* has demonstrated a similar trend for the color difference perception threshold.

The visibility impairment from a wide plume passing near the observer (which subtends a large angle) is correctly evaluated by comparing the calculated contrast and color difference to thresholds that account for the angle subtended by the plume. This paper describes procedures for calculating subtended angles, and the commensurate improved contrast and color difference thresholds, from information available in PLUVUE, including for lines of sight oblique to the plume. These calculation methods were incorporated into a post-processor, which compares contrast and color difference from PLUVUE with improved thresholds for many PLUVUE output files.

A detailed analysis for multiple observer locations over a five-year period for a specific emission source and Class I area showed that the actual frequency of visibility impairment (exceeding thresholds that account for subtended angle) is much less than that calculated using the conservative FLAG guideline thresholds.

INTRODUCTION

Visibility Impairment Analysis

The Clean Air Act Amendments require that new or modified major sources of emission of sulfur dioxide (SO_2), nitrogen oxides (NO_x), and/or particulate matter (PM) evaluate the effects of plumes on visibility in nearby Class I areas. Permit applications are reviewed for visibility impairment by the Federal Land Managers (FLM) for the Class I area.

The Environmental Protection Agency (EPA) has prescribed a methodology for the assessment of visibility impairment impacts[1], consisting of three levels of analysis arranged in increasing order of detail and refinement. If a simplistic analysis using conservative assumptions demonstrates insignificant impacts below screening threshold values, the more complex analysis need not be performed.

This paper describes the visibility impairment modeling recently performed for an emission source proposed to be located about 24 km from the closest boundary of a National Park. An initial assessment indicated that screening analysis would not be adequate, and that a Level 3 detailed analysis using the PLUVUE II model would be required.

The PLUVUE II model uses a Gaussian dispersion model to calculate hourly-average downwind concentrations, then calculates the contrast and color difference due to the plume relative to the background for lines of sight from an input observer location to up to 16 points along the downwind axis. It takes into account the apparent position of the sun, (which depends on season and time of day), and the distance from the observer to the background, in order to ensure that the plume is not hidden from the observer by a background object. Typically, this analysis is performed for every daylight hour over a five-year period for which the wind blows the plume centerline over the Class I area.

Levels of Concern for PLUVUE II Analysis

The Federal Land Managers' Air Quality Related Values Workgroup (FLAG)[2] has set Levels of Concern for two measures of visibility impairment due to a pollutant plume:

- <u>Plume Contrast</u>: A measure of the relative brightness (positive) or darkness (negative) of a plume as compared to its background. Since both negative and positive values can occur, the Level of Concern was set for the absolute value of the contrast at $|C| < 0.02$.

- <u>Color Difference (ΔE):</u> A measure of the color of the plume relative to its background, calculated over the entire visible spectrum, for which the Level of Concern was set to $\Delta E < 1.0$.

Perception Thresholds and Plume Subtended Angle

Perception research by Howell and Hess (1978)[3] showed that the human eye is most sensitive to contrast between a plume and the background for plumes whose apparent width (angle subtended by the plume relative to the observer) ranges from 0.2 to 1.0 degree. The contrast which is required to be perceived by the human eye for wider plumes increases rapidly for larger subtended angles.[3]

Similarly, Willard Richards, *et al*[4] have demonstrated that the threshold at which the human eye can detect color difference (ΔE) also increases rapidly as a function of the plume subtended angle, for angles larger than about one degree.

The Levels of Concern for contrast and color difference established in the Federal Land Managers' Air Quality Related Values Workgroup (FLAG) document[2] are near the minima of the perception curves, which occur at small subtended angles where the human eye is most sensitive to contrast and color difference.

Modeling experience has shown that the highest contrast and color differences calculated by PLUVUE II occur when the plume centerline passes relatively close to an observer in the Class I area. A plume emitted from a source tens of kilometers away can be hundreds of meters wide at the observer's line of sight, and therefore can subtend an angle much larger than 1 degree. A wide plume may not actually be visible to the observer, even if its contrast or color difference exceeds the low FLAG thresholds[2] which apply to narrow plumes.

In some cases, where the plume centerline passes extremely close to the observer location, the observer may be inside the plume, and therefore unable view the background used in the PLUVUE II calculations.

Purpose of This Paper

This paper investigates the effect of comparing contrast and color difference values calculated by PLUVUE II to perception thresholds which vary as a function of subtended angle, which are more indicative of the observer's actual ability to perceive the plume than a fixed threshold based on a narrow plume. Equations are presented for the variation of contrast and color difference perception thresholds as a function of subtended angle, based on the perception research performed by Howell and Hess[3] and Richards, *et al.*[4].

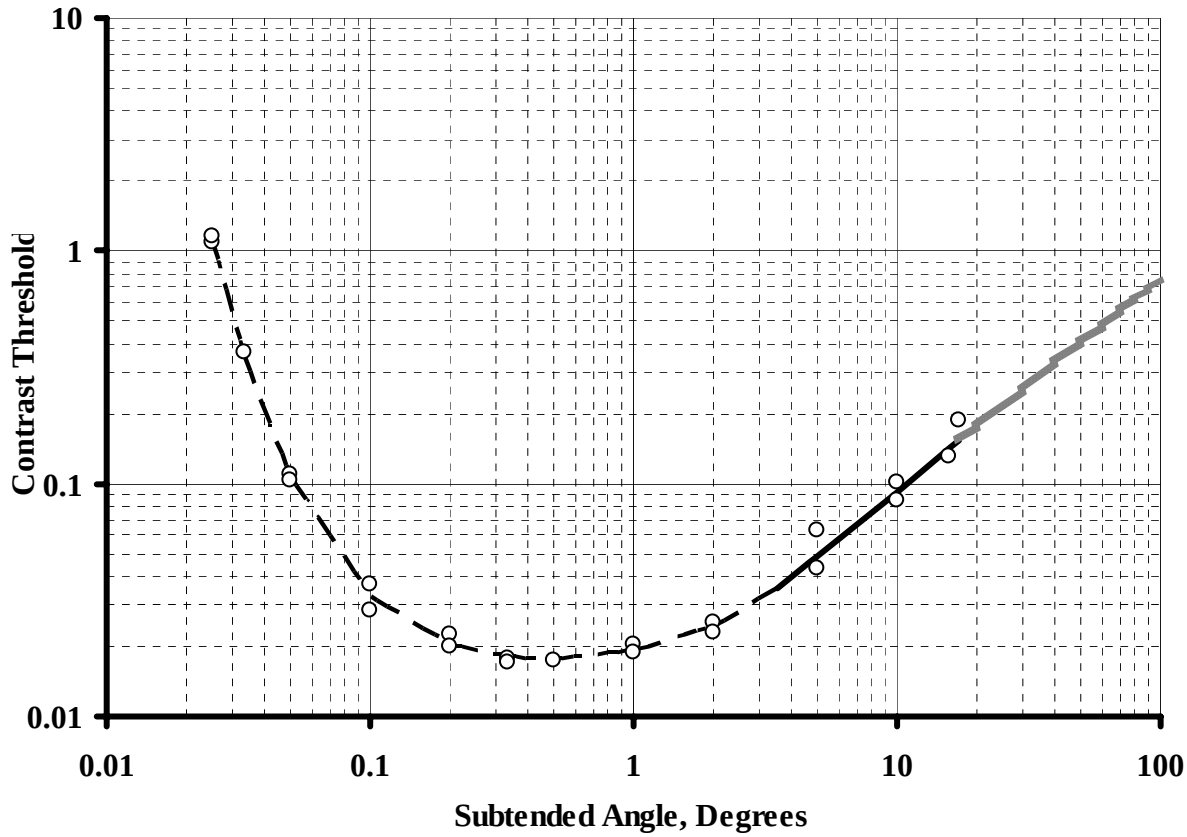
A method is presented to calculate the angle subtended by a plume as a function of source and observer location, downwind distance along a plume centerline, and plume parameters calculated by the PLUVUE II program. This method was incorporated into post-processing software used to summarize and evaluate the results from large numbers of PLUVUE II output files. This software was used to compare the frequency with which contrast and color difference calculated by PLUVUE II exceed variable perception thresholds as functions of subtended angle, with the frequency of exceeding fixed (FLAG) Levels of Concern.

EXPERIMENTAL METHODS

Contrast Threshold and Subtended Angle

Figure 1 below presents a log-log graph of the contrast perception thresholds derived from measurements by E. R. Howell and R. F. Hess (1978)[3] as a function of the angle subtended by the plume, in degrees. The EPA guidance[1] for contrast perception thresholds was based on Howell and Hess' observations[3] of five-cycle sine-wave patterns. They report that the perception thresholds for two observers were higher when viewing a one-cycle sine-wave pattern, which is more representative of a Gaussian plume profile.[4] When this correction is applied to the contrast thresholds measured for five-cycle sine-wave patterns[3], the results are shown by the open circles on Figure 1.

Figure 1: Contrast Threshold as a Function of Subtended Angle (Howell and Hess, 1978)



The Level of Concern for contrast recommended in the FLAG document[2] ($|C| < 0.02$) corresponds to the lowest thresholds measured for subtended angles between 0.2 and 1.0 degree. However, for subtended angles greater than 1 degree, representative of the wide plumes passing close to an observer in a Class I area, the minimum contrast at which the observer can perceive the plume increases with subtended angle.

At the largest subtended angle for which measurements were made by Howell and Hess[2] (17.24^o), the contrast threshold is nearly an order of magnitude higher than the FLAG Level of Concern[1].

The dashed line in Figure 1 represents a fourth-order polynomial regression of the logarithm of contrast threshold as a function of the logarithm of subtended angle, for the experimental values at angles up to (and including) 5.0 degrees:

$$\log C_t = -1.713 + 0.207(\log\phi) + 0.310(\log\phi)^2 + 0.183(\log\phi)^3 + 0.311(\log\phi)^4 \qquad \text{(Eq. 1)}$$

where the symbol "log" represents a logarithm to the base ten (10), and:

C_t = contrast perception threshold

ϕ = angle subtended by plume, degrees

For subtended angles less than 5 degrees, Equation 1 fits the Howell and Hess[3] data with a root-mean-square (RMS) error of 8.6%, but it tends to over-estimate contrast thresholds at higher angles. Since all coefficients in Equation 1 are positive, extrapolation beyond the range of the data might result in unrealistically high predicted contrast thresholds.

A more reasonable extrapolation of the Howell and Hess[3] data to subtended angles above the range of measurement was obtained by performing a linear regression (in log-log coordinates) on the last six data points (from 5° to 17.24^o inclusive):

$$\log C_t = -1.950 + 0.917(\log\phi) \qquad \text{(Eq. 2)}$$

This line crosses Equation 1 at $\phi = 2.61^\circ$ and $\phi = 4.67^\circ$, but the slope of Equation 1 does not match the slope of Equation 2 at these points. In order to ensure a smooth transition between the two regressions, the angle was found at which the slopes of the two curves were equal.

Differentiating Equation 1 with respect to $(\log\phi)$, setting the result equal to 0.917 (the slope of Equation 2), and solving for ϕ results in equal slopes at $\phi = 3.53^\circ$. The intercept of the straight line (Equation 2) was then adjusted so that the calculated contrast thresholds were equal for the two equations at $\phi = 3.53^\circ$, which resulted in a modified linear regression:

$$\log C_t = -1.932 + 0.917(\log\phi) \qquad \text{(Eq. 3)}$$

Equation 3 fits the Howell and Hess data[3] for angles from 5.0 to 17.24 degrees (inclusive) with an RMS error of 14.1%, and is plotted as the solid dark line in Figure 1. The extrapolation of this equation to higher subtended angles is shown by the gray line in Figure 1.

In the post-processing software for PLUVUE II, the improved contrast threshold was calculated using Equation 1 for subtended angles less than 3.53^o, and using Equation 3 for subtended angles greater than 3.53^o.

Color Difference Threshold and Subtended Angle

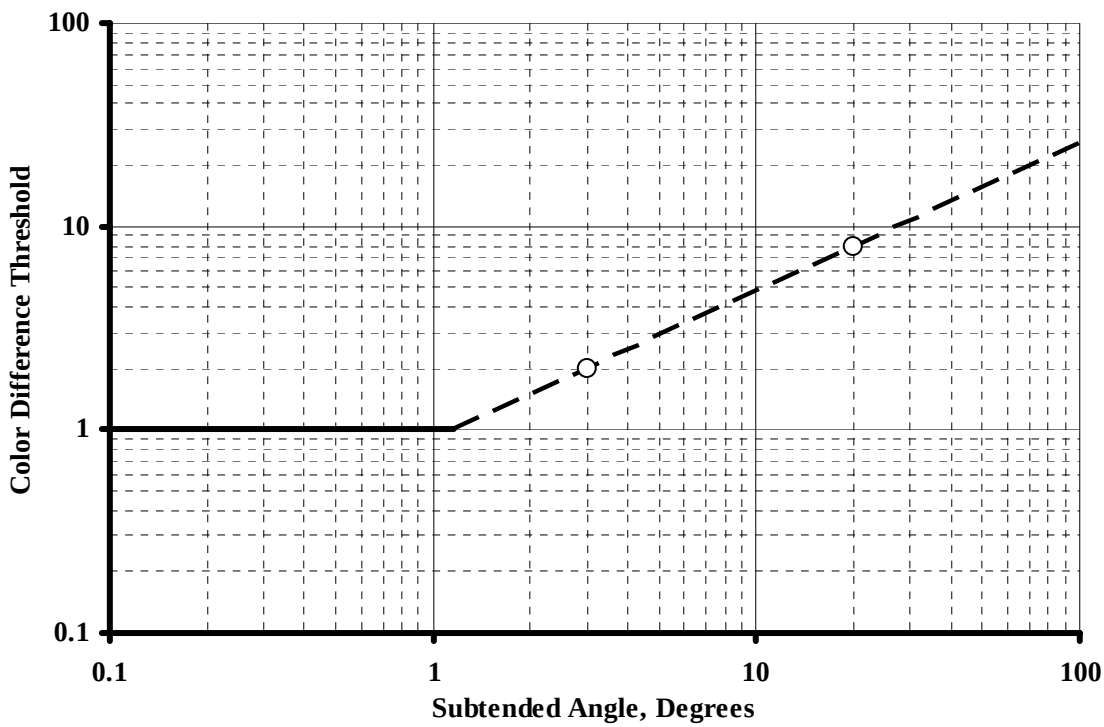
L. Willard Richards, *et al.*[4] investigated the variation of the color difference perception threshold as a function of plume subtended angle. A preliminary theoretical equation was developed by multiplying an earlier regression of the Howell and Hess[3] contrast threshold data appearing in the original EPA guidance[1] by a fixed constant, assuming that color difference and contrast perception thresholds are proportional at all subtended angles.

This theoretical equation predicts a color difference perception threshold of $\Delta E_1 = 2.0$ at a subtended angle of $\phi_1 = 3^\circ$, and $\Delta E_2 = 8.0$ at a subtended angle of $\phi_2 = 20^\circ$. If a straight line is drawn between these two points (open circles on Figure 2) on log-log coordinates, the equation of this line for the color difference threshold ΔE_t is a power-law function:

$$\Delta E_t = 0.896(\phi)^{0.731} \qquad \text{(Eq. 4)}$$

This equation is plotted as the dashed line in Figure 2 below. If ΔE_t is set to 1.0 and Equation 4 is solved for ϕ, it is found that the improved color difference threshold using Equation 4 is equal to the FLAG Level of Concern[1] of $\Delta E_t = 1.0$ for a subtended angle of $\phi = 1.16^\circ$.

Figure 2:
Color Difference Threshold as a Function of Subtended Angle



In the post-processing software for PLUVUE II, the improved color difference threshold was calculated using Equation 4 (dotted line on Figure 2) for subtended angles greater than 1.16^o, and was assumed equal to the FLAG Level of Concern[1] of $\Delta E_t = 1.0$ (solid black line on Figure 2) for subtended angles less than 1.16^o. This correction to the color difference threshold was approved by the National Park Service in the visibility modeling protocol for a proposed emission source near a National Park.

In 2005, Willard Richards *et al*[4] developed a computer application, called the Plume Color Demonstration Program[4], which displayed on a computer monitor the appearance of a Gaussian plume with a given color, intensity, and plume width against a background of a given color. The ratio of the width of the virtual "plume" on the monitor screen to the distance of an observer to the screen can be used to define the angle subtended by the virtual "plume".

Richards, *et al.*[4] used this program to demonstrate that the color difference perception thresholds were significantly higher than those predicted by Equation 4 over a range of subtended angles from 1.75^o to 10.49^o.

However, the more conservative thresholds given by Equation 4 were used for visibility impairment modeling for the proposed emission source, since they had already been approved for use in the modeling protocol by the National Park Service.

PLUVUE II Pre-Processing and Post-Processing Software

Power Plant Permitting Project

This study of the effect of subtended angle on contrast and color difference thresholds in PLUVUE II was part of the process of permitting a proposed power plant, to be located about 23.7 km east-southeast of the closest boundary of a National Park.

A review of the terrain, overlooks, and scenic vistas in the Class I area by the Federal Land Managers resulted in the identification of seven observer locations within the National Park, for which the visibility impacts were to be calculated.

The EPA *Workbook for Plume Visual Impact Screening and Analysis*[1] recommends a minimum "offset" angle of 11.25^o (between the downwind axis and the azimuth from the source to the observer location) as the "worst-case" wind direction to be analyzed. In this case, however, the arc of wind directions which blow over the National Park is only 15° wide (109° to 124°), and application of the 11.25^o minimum offset angle for centrally-located observer locations would eliminate all wind directions from consideration.

For each observer location, the analyses were performed for all daylight hours over a five-year period for which the wind would blow the plume centerline over the Park, with wind directions originally measured to the nearest 10 degrees "randomized" to 1-degree increments.

According to hourly meteorological data for the years 1990 through 1994 (inclusive) obtained from a nearby weather station, there were 901 such hours to be modeled. Modeling for each of seven observer locations required a total of 6,307 executions of the PLUVUE II model.

Automated PLUVUE II Processing Software

Due to the large amount of data to be processed, and the repetitive nature of many of the inputs, an automated method was developed for generating PLUVUE II input files, executing a series of PLUVUE II files batchwise, and summarizing PLUVUE II output in a compact and user-friendly form. Three software applications were developed:

- PLUVUGEN: a program to combine input data from various input files, generate PLUVUE II input files, and a batch file that will execute them, for a given observer location and wind direction;

- PLUVUBAT: a program to execute PLUVUE II batchwise according to the batch file generated by PLUVUGEN;

- RDPLUVUE: a post-processor that extracts useful information from PLUVUE II output files, and summarizes the number of hours for which contrast and color difference calculated by PLUVUE II exceeded Levels of Concern thresholds, for a given observer location and wind direction.

The PLUVUGEN Pre-Processor

For a given observer location and wind direction, the PLUVUGEN pre-processor combines data from five input files to generate PLUVUE II input files for all daylight hours in the hourly meteorological data file for which the wind blows from the given direction. The PLUVUGEN pre-processor substitutes the appropriate meteorological data for the selected hours in each PLUVUE II input file.

A common file is used for “default options” for all runs, as well as a common file containing stack and emission data. Another input file contains information specific to the observer location, and another input file contains information specific to a given combination of observer location and wind directions.

This “wind-direction-dependent” input file includes a set of downwind distances from the emission source, which define points the plume centerline. PLUVUE II is coded to calculate contrast and color difference for “lines of sight” from the observer location to each point on the centerline. The downwind distances are chosen so that the azimuths of the lines of sight are close to fixed 15° increments of azimuth at which distances from the observer to the background object are input to PLUVUE II.

The PLUVUGEN pre-processor also calculates inclination angles from the observer to the farthest visible background object along each line of sight.

The RDPLUVUE Post-Processor

For a given observer location and wind direction, the RDPLUVUE post-processor reads the values of contrast and color difference calculated by PLUVUE II for each downwind distance, and prints a one-line summary of the highest values of contrast and color difference for each modeled hour, and whether they exceed the appropriate thresholds.

The RDPLUVUE post-processor excludes some situations from consideration, such as if the plume centerline is behind a background object relative to the observer, or outside the Park boundary. It also prints warning messages of other conditions that might prevent the observer from seeing the plume, such as poor natural visibility due to rain, snow, or fog.

The PLUVUE II model calculates the inclination angle β_i from the observer location to the plume centerline at each downwind distance x_i. If this angle is greater than the inclination angle to the background calculated by PLUVUGEN, the plume can only be viewed against sky background. In this case, the RDPLUVUE program only takes into account contrast and color difference values calculated by PLUVUE II against sky background, not against ground-level (white, gray, or black) backgrounds.

The calculations of subtended angle, and adjustments to contrast and color difference thresholds based on subtended angle, are performed by the RDPLUVUE post-processor, using information output by PLUVUE II for each line of sight. The program also has an option to bypass these calculations and compare the contrast and color differences calculated by PLUVUE directly to the fixed FLAG Levels of Concern.[2]

Calculation of Angle Subtended by Plume

Data Available from PLUVUE II

The PLUVUE II model normally calculates contrast and color difference along up to 16 lines of sight extending from the observer location through the plume. Each line of sight is defined by a line from the observer location through a point on the plume centerline whose distance x_i downwind of the emission source has been input to PLUVUE II.

The PLUVUE II model calculates the orientation of each line of sight relative to the sun position based on the following input information:

X_s = Universal Transverse Mercator (UTM) easting coordinate of stack, m
Y_s = UTM northing coordinate of stack, m
X_o = UTM easting coordinate of observer location, m
Y_o = UTM northing coordinate of observer location, m
z_o = Elevation of observer location above sea level, m
ω = Direction from which wind is blowing, degrees clockwise from north.

The PLUVUE II model contains a Gaussian dispersion model, which calculates the following parameters for each downwind distance x_i:

h_{ci} = height of plume centerline above the ground, m

σ_{yi} = standard deviation of crosswind dispersion, m

σ_{zi} = standard deviation of vertical dispersion, m

Since the PLUVUE II model assumes that the plume centerline follows the terrain, the elevation of the plume centerline z_{ci} above sea level at a downwind distance x_i is:

$$z_{ci} = z_{gi} + h_{ci} \qquad \text{(Eq. 5)}$$

where z_{gi} is the input elevation of the ground above sea level at downwind distance x_i. All the information mentioned above is available to the RDPLUVUE post-processor.

Rotation of Coordinate Axes

In order to simplify the calculations, a wind-based coordinate system is defined whose origin is at sea level directly below the emission source, with the *x* axis extending downwind, and the positive *y* axis to the right when looking downwind. In this coordinate system, the coordinates of a point *C* on the plume centerline at a distance x_i downwind are $(x_i, 0, z_{ci})$. The downwind and crosswind coordinates of the observer location x_o and y_o are obtained from the UTM coordinates *X* and *Y* by rotation of axes as follows:

$$x_o = (X_o - X_s)\sin\omega + (Y_o - Y_s)\cos\omega \qquad \text{(Eq. 6)}$$

$$y_o = (X_o - X_s)\cos\omega - (Y_o - Y_s)\sin\omega \qquad \text{(Eq. 7)}$$

Equivalent Plume Width

In the contrast perception experiments, the plume subtended angle is calculated using the width of one cycle of the sine wave pattern[3]. The best agreement between sine-wave and Gaussian patterns is obtained when the subtended angle for Gaussian plumes is calculated using four times the Gaussian sigma. Thus, the Gaussian plume width is 2σ on each side of the plume centerline.

In a Gaussian dispersion model, at a given downwind distance x_i, the concentration distribution through the plume in a crosswind vertical plane at $x = x_i$ is given by:

$$c(y,z) = c_c \exp\left[\frac{-y^2}{2\sigma_{yi}^2}\right]\exp\left[\frac{-(z - z_{ci})^2}{2\sigma_{zi}^2}\right] \qquad \text{(Eq. 8)}$$

where c_c represents the concentration at the plume centerline.

For an observer at the same elevation and downwind distance as the plume centerline ($z_o = z_{ci}$ and $x_o = x_{ci}$), whose line of sight is perpendicular to the plume centerline, the pollutant concentration at the plume edges $z = z_{ci} \pm 2\sigma_{zi}$ equivalent to the one-cycle sine-wave pattern, from Equation 8, is given by:

$$c(y = 0, z = z_{ci} \pm 2\sigma_{zi}) = c_c \exp(-2) = \frac{c_c}{e^2} \qquad \text{(Eq. 9)}$$

For an observer whose line of sight is oblique to the plume centerline, the apparent plume width is defined by two points on a line through the plume centerline (at the given downwind distance x_i) perpendicular to the line of sight, where the pollutant concentration is c_c / e^2. According to Equation 8, an envelope of constant concentration c_c / e^2 is given by:

$$\frac{y^2}{4\sigma_{yi}^{\ 2}} + \frac{(z - z_{ci})^2}{4\sigma_{zi}^{\ 2}} = 1 \qquad \text{(Eq. 10)}$$

which defines an ellipse centered at $(x_i, 0, z_{ci})$, whose crosswind semi-axis is $2\sigma_{yi}$, and whose vertical semi-axis is $2\sigma_{zi}$, in a vertical plane at $x = x_i$. The apparent plume width for the observer is defined by the two points where a line perpendicular to the line of sight in the plane $x = x_i$ crosses the ellipse defined by Equation 10.

This is illustrated in Figure 3 on the next page, where point *C* on the plume centerline is the center of an ellipse in a plane perpendicular to the plume centerline. The line E_1E_2 is perpendicular to the line of sight *OC* from the observer *O* to the plume centerline at point *C*, and crosses the ellipse at points E_1 and E_2.

Angle Subtended by Plume

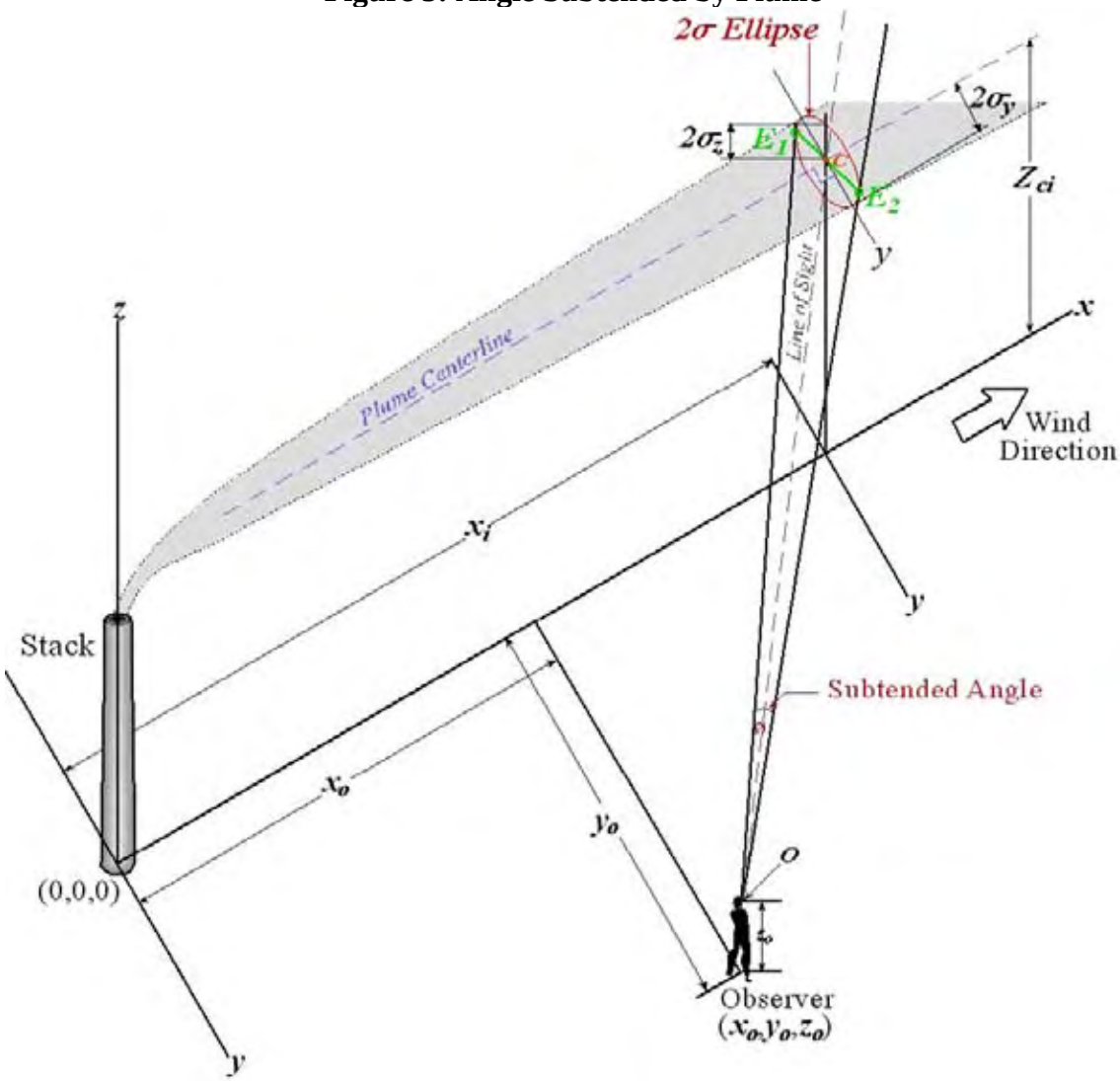
The angle subtended by the plume boundary is calculated by applying the law of cosines to the triangle formed by the observer point *O* and the two boundary points E_1 and E_2 on the ellipse:

$$\cos\phi = \frac{d_{o1}^{\ 2} + d_{o2}^{\ 2} - d_{12}^{\ 2}}{2 d_{o1} d_{o2}} \qquad \text{(Eq. 11)}$$

where:

d_{12} = distance from point E_1 to E_2 on the ellipse, m
d_{o1} = distance from observer location to point E_1 on the ellipse, m
d_{o2} = distance from observer location to point E_2 on the ellipse, m

Figure 3: Angle Subtended by Plume



Summary of Calculation Procedure

For a given PLUVUE II output file, the RDPLUVUE post-processor first calculates the downwind and crosswind coordinates of the observer location using Equations 6 and 7. Then, for each downwind distance x_i, the program calculates the angle subtended by the plume as follows:

1) Calculation of coordinates of the points on the ellipse which define the plume width.

2) Calculation of distances between the observer location and each point on the ellipse, and between the two points, from their coordinates.

3) Calculation of the subtended angle using Equation 11.

Once the subtended angle has been calculated, the contrast threshold C_t is calculated using either Equation 1 (if $\phi \leq 3.53^{\circ}$) or Equation 3 (if $\phi > 3.53^{o}$).

The color difference threshold ΔE_t is calculated using either Equation 4 (if $\phi > 1.16^{\circ}$), or set to the FLAG Level of Concern[2] (if $\phi \leq 1.16^{\circ}$).

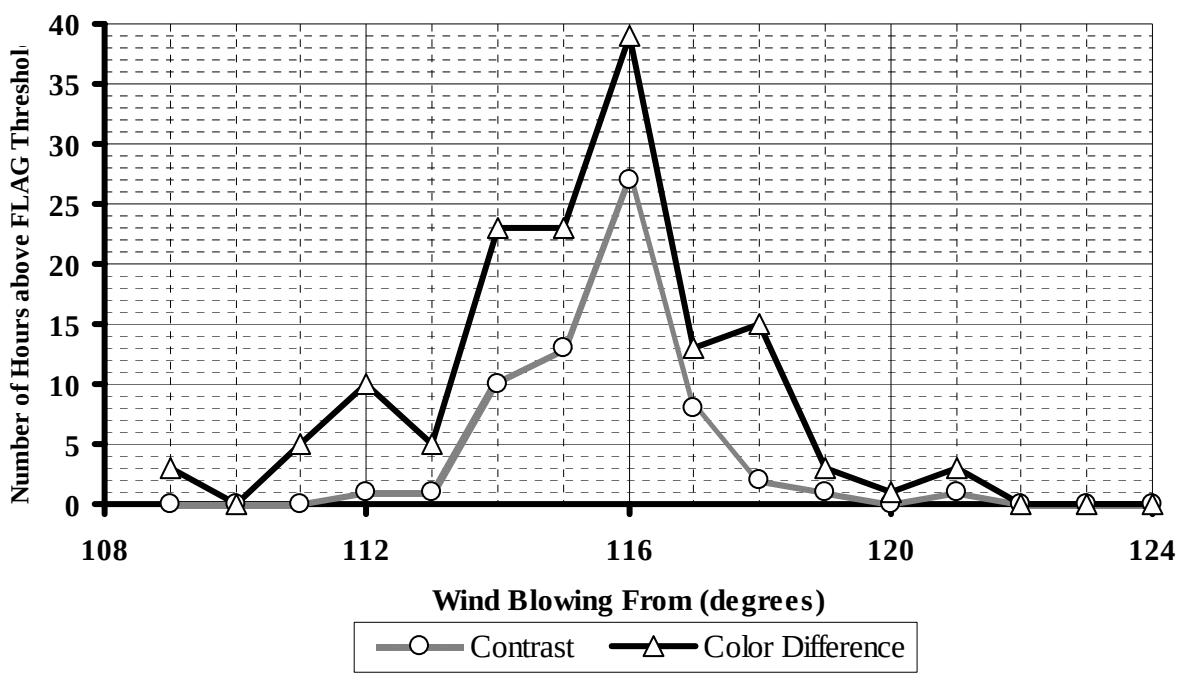
RESULTS AND DISCUSSION

Comparison of PLUVUE Output to FLAG Thresholds

For each of the seven observer locations, the PLUVUE II model was executed for each of the 901 hours for which the wind direction blew the plume centerline over the National Park. The RDPLUVUE post-processor was used to determine the number of hours for which the contrast and color difference calculated by PLUVUE II exceeded either the fixed Federal Land Managers' Air Quality Related Values Workgroup (FLAG) thresholds[2], or thresholds that account for subtended angle as described above.

The number of hours for which contrast and color difference exceeded the fixed FLAG thresholds[2] depended strongly on the wind direction, reaching a peak for the wind direction which blows the plume centerline directly over the observer location. Figure 4 below presents a graph of the number of hours for which the contrast (gray line) and color difference (black line) were greater than the FLAG thresholds for a particular observer location (H), which would be directly downwind of the emission source for a wind blowing from 115.9^{o}.

Figure 4: Number of Hours Above FLAG Thresholds at Observer H as a Function of Wind Direction



This graph clearly shows that the number of hours above the FLAG threshold[2] reaches a maximum when the wind blows the plume nearly directly at the observer location, and decreases rapidly in either direction. Since each wind direction represents a composite sample of many different combinations of dispersion conditions (wind speed, temperature, humidity and stability), it also indicates that the calculated contrast and color differences are highest when the wind blows the plume closest to the observer location.

For this observer location, a wind from 116° blows the plume centerline nearly directly over the observer location, and the observer would be inside the plume, and unable to distinguish it from the background. For winds blowing from 114° through 118° (offset angle < 2.1^o), a line of sight through a point along the plume centerline either upwind or downwind of the observer travels a long trajectory through the plume, resulting in high values of contrast and color difference. However, the plume would also subtend very large, possibly obtuse (> 90°) angles, and the observer would not actually be able to discern such a wide, diffuse plume against the background, according to the graphs in Figure 1 and Figure 2.

Figure 4 shows that there were only three hours above the FLAG thresholds[2] for offset angles greater than 5.1^o (outside of the range of wind directions from 111° through 121.2^o), which is less than half of the minimum offset of 11.25^o recommended by the EPA *Workbook for Plume Visual Impact Screening and Analysis*[1].

It should be noted that the number of hours is higher for plumes passing to the south of the observer (wind directions < 116°) than for plumes passing to the north of the observer (wind directions > 116°). For plume passing to the south of the observer, a line of sight to the plume centerline would pass closer to the position of the sun (which tends to highlight plume contrast), than for a back-lit plume passing to the north of the observer.

When compared to the fixed FLAG thresholds, trends similar to that shown in Figure 4 were found for six out of seven observer locations, with the maximum number of hours above thresholds occurring for the wind direction which blew the plume closest to each observer location, decreasing rapidly as the offset angle increased in either direction. For the seventh observer location, only one hour exceeded the FLAG threshold, so no trend could be observed.

Comparison of PLUVUE II Output to Improved Thresholds

The comparison of PLUVUE II output to thresholds that account for subtended angle showed that there were only four hours over the entire five-year period during which the calculated contrast or color difference exceeded the improved thresholds at any of the seven observer locations.

Three of these hours occurred during early morning, where the stability class listed in the hourly meteorological data file was E or F (very unfavorable for dispersion), which normally only occur at night. The other hour occurred shortly before sunset, with the sun only 2.2 degrees above the horizon, and sensitivity studies have shown that contrast and color difference values calculated by PLUVUE II can be unrealistically high for sun angles less than 5° above the horizon.

Table 1 below compares the number of hours (over the five-year period) during which the contrast and color difference values calculated by PLUVUE II for the proposed emission source were greater than the fixed FLAG thresholds, or greater than the thresholds that account for the angle subtended by the plume.

Table 1: Number of Hours Above FLAG and Improved Thresholds

	Observer Location==>	B	H	M	N	P	R	S
Contrast: Number of Hours >								
	FLAG Threshold	35	64	41	61	17	21	0
	Threshold Adjusted for Subtended Angle	2	1	2	3	1	1	0
Color Difference: Number of Hours >								
	FLAG Threshold	98	143	131	110	30	51	1
	Threshold Adjusted for Subtended Angle	2	2	1	2	1	1	0
Number of Hours > Either Threshold								
	FLAG Thresholds	100	148	137	118	31	52	1
	Thresholds Adjusted for Subtended Angle	2	2	2	3	1	1	0

For the proposed emission source, comparison of PLUVUE II output to the fixed FLAG thresholds (intended for narrow plumes which subtend angles less than 1.16^{o}) would suggest that visibility impairment would occur during 100 hours or more (over a five-year period) at four of the seven observer locations. However, when the same PLUVUE II results are compared to thresholds which measure the observer's ability to perceive the actual wide plume, visibility impairment would only occur at a maximum of 3 hours at any observer location, only under extreme conditions (night-time stability and/or low sun angle).

The reason for this difference is suggested by Figure 4, where most of the hours above the FLAG thresholds occur for offset angles (between the downwind axis and the line from the source to the observer) less than 3 degrees. At downwind distances of more than 23.7 km (the closest park boundary to the emission source), for daytime stability classes (A, B, C, or D), $\sigma_{yi} \geq 1000m$, and the plume ellipse (Equation 9) for n = 2 is at least 800 m high and 4000 m wide. For offset angles less than 3°, the observer location is less than 2 km crosswind from the plume centerline, so that the plume subtends large angles. According to Figures 1 and 2, the observer cannot distinguish the wide, diffuse plume from the background, even if the calculated contrast and/or color difference are above the FLAG thresholds.

These results (Figure 4 and Table 1) show that at low offset angles, the plume subtends a large angle at the observer location, and it may not be perceptible by the observer, so that the FLAG thresholds intended for low subtended angles are not applicable.

In Table 1, it should be noted that the number of hours above either threshold were less than the sum of the number of hours of contrast above threshold, and the number of hours of color difference above threshold. There were many hours for which both contrast and color difference exceed the FLAG threshold, and the color difference was more likely to exceed the FLAG threshold than contrast, at all observer locations.

Similarly, there were only four hours during which the contrast or color difference calculated by PLUVUE II exceeded the improved thresholds, although the sum of the number of hours for all observer locations is greater than 4. The same four hours resulted in exceedances of adjusted thresholds at multiple observer points.

CONCLUSIONS

The fixed contrast and color difference thresholds given in the Federal Land Managers' Air Quality Related Values Workgroup (FLAG) document[2] are based on narrow plumes which subtend angles of less than 1.16^{o} at the observer location.

Perception threshold research[3,4] has shown that the thresholds at which the human eye can distinguish contrast and color difference between a plume and the background increase as a function of the angle subtended by the plume. Regression equations are presented for thresholds at which contrast and color difference can be perceived as a function of subtended angle.

Post-processing software has been developed which can calculate the angle subtended by a plume, whose width is defined by a two-sigma ellipse around the plume centerline, relative to a given observer location along a given line of sight. This software can compare contrast and color difference values calculated by PLUVUE II to thresholds that account for subtended angle, using the regression equations described above.

A case study for a proposed emission source to be located 24 km from a National Park shows that the probability of PLUVUE II calculating contrast or color difference values greater than the FLAG thresholds is greatest at low offset angles (where the downwind axis passes close to the observer location).

Under these conditions of low offset angles, the plume subtends large angles relative to the observer location (or the observer is inside the plume), and the observer often cannot distinguish such a wide, diffuse plume from the background, despite the exceedance of the FLAG thresholds intended for narrow plumes.

The EPA *Workbook for Plume Visual Impact Screening and Analysis*[1] recommended a minimum offset angle (between the downwind axis and a line from the emission source to the observer) of 11.25^{o} for visibility impairment analysis. Visibility impairment modeling at lower offset angles leads to an unrealistically high number of exceedances of the FLAG thresholds, because the subtended angles are much larger than those for which the FLAG thresholds were intended.

Adjustment of contrast and color difference thresholds as functions of subtended angle (using appropriate post-processing software) enable a more realistic modeling of visibility impairment at low offset angles, while taking into account the difficulty of the observer to distinguish a wide, diffuse plume from its background, as compared to a narrow, compact plume.

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KEY WORDS

Visibility, Class I area, modeling, PLUVUE II, contrast, color difference, thresholds, subtended angle.

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Analysis of the Potential for a Coal-Fired Power Plant to Cause Visibility Impairment in a National Park

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INTRODUCTION

This paper describes the methods used to evaluate the potential for a proposed new source to cause visibility impairment in a national park under conditions where the regulatory model described in the U.S. Environmental Protection Agency (EPA) guidelines was not entirely applicable. The visibility analysis examined the potential impacts of the Healy Clean Coal Project (HCCP), a proposed 50-MW coal-fired power plant to be built in Healy, Alaska, about 6 km north of Denali National Park and Preserve (DNPP). The analysis used the PLUVUE I visibility model to calculate the ambient concentrations of species in the plume that have the potential to cause visible effects. These calculations used the plume rise, plume transport, plume diffusion, and plume chemistry modules in PLUVUE I (which are the same as in the regulatory model PLUVUE II), but did not use the optical module. The optical module was not applicable when the sun was within about 10° of the horizon, which is typically the case in winter, the season when limited plume dispersion is most likely. Therefore, the optical effects were determined in separate calculations, which will be described. Results indicated that almost all of the potential impacts would be caused by oxides of nitrogen (NO_x) emissions. The visual angle subtended by the plume was calculated and used to show that the threshold for the visual perception of the plume was a contrast of 0.04, which corresponds to a color difference $\Delta E = 4$ and a nitrogen dioxide (NO_2) burden in the sight path of 150 ppbv·km.

BACKGROUND

The HCCP, proposed by the Alaska Industrial Development and Export Authority (AIDEA), was selected in December 1989 for cost-shared funding in the third round of the Clean Coal Technology (CCT) Program. The goal of the CCT Program is to demonstrate advanced, more efficient, economically feasible, and environmentally acceptable coal technologies for commercialization into the U.S. energy marketplace. The HCCP will demonstrate novel technologies using a new 50-MW coal-fired power generating facility to be built adjacent to the existing 25-MW Healy Unit No. 1, a conventional pulverized-coal unit owned and operated by Golden Valley Electric Association, Inc. (GVEA) in Healy, Alaska. The proposed project is located approximately 130 km southwest of Fairbanks and 400 km north of Anchorage (Figure 1).

The HCCP will be fueled with a blend of low-sulfur coal and waste coal (containing an average of 0.15% sulfur and 17% ash) supplied by Usibelli Coal Mine, Inc., from an open-pit coal mine located about 6 km north of the site. Waste coal is either low-grade coal or overburden- or underburden-contaminated coal of quality that normally is too poor to be used. Construction of the project is expected to begin in April 1995 and be completed in late 1997. After an approximate 18-month demonstration and testing period, commercial operation of the project is anticipated to begin in 1999.

The project is intended to demonstrate the combined removal of sulfur dioxide (SO_2), NO_x, and particulate matter using innovative combustion and flue gas cleanup technologies. The combustion technology is an entrained combustion system with limestone injection to capture SO_2 in the flue gas. The main combustion sections operate at a slight air deficiency to reduce the amount of NO_x produced. The postcombustion technology is a spray dryer absorber for removal of particulate matter and for a second stage of SO_2 removal. The technologies are dependent on each other as part of the integrated system. A baghouse provides further capture of particulate matter and SO_2 before the flue gas exits through the stack.

CONCERNS OF THE NATIONAL PARK SERVICE

Much attention has recently been given to the conflict between industrial development and preservation of the pristine nature of the National Park Service's (NPS's) nationwide park system. A large portion of this dispute focuses on air quality, particularly the clarity of the atmosphere as it affects visibility within the national parks. Many visitors to the parks are unable to fully enjoy some of the beautiful and dramatic views that would prevail in the absence of anthropogenic air pollution.[1] Although Congress in 1977 established a national goal of correcting and preventing pollution-related visibility impairment affecting national parks, little progress has been made to date.[1] As in other areas of environmental concern, this conflict is the result of a value judgment decision between the preservation of scenic beauty and the use of natural resources for economic development.[2]

In this case, because the HCCP site is only 6 km north of the nearest border of DNPP, a "crown jewel" of the park system with pristine air quality, the potential for the project's emissions to degrade visibility within the park was of great concern to the park service from the project's inception. DNPP is designated a federal Prevention of Significant Deterioration (PSD) Class I area where stringent standards apply to severely limit any degradation of air quality. Although there have been no known visibility impacts associated with the existing Healy Unit No. 1, NPS was concerned that the simultaneous operation of the HCCP and Unit No. 1 might result in emissions above a threshold that would trigger perceptible effects. Therefore, the goal of the visibility analysis was to generate predictions which would be conservative (would form an upper bound of expected results) while not being so conservative that they were unrealistic. The results of the visibility analysis were incorporated into the PSD permit application prepared by AIDEA[3] and the Environmental Impact Statement prepared by DOE.[4] As part of an agreement with the park service, AIDEA and GVEA have agreed to add SO_2 and NO_x emission controls to Unit No. 1 and to conduct a visibility monitoring program.

METHODOLOGY

The visibility analysis focused on the perceptibility of a plume as viewed from the DNPP Visitor Access Center, located 13.5 km south of the HCCP site and 7.5 km south of the northern boundary of the park (Figure 1). These views were expected to be most susceptible to the effects of the emissions from Healy Unit No. 1 and the HCCP. The DNPP Visitor Access Center is situated on a knoll overlooking the Nenana River near the entrance to the park and is visited by most travelers to the park. The primary views are to the north (down the Nenana River Valley toward the HCCP site) for 7.5 km to the park boundary and to the south (up the Nenana River Valley away from the HCCP site) for 14.5 km to the boundary. The view to the east is confined to about 0.5 km within the park. The limited view to the west is not expected to be affected greatly by northerly winds that tend to continue transporting a plume to the south up the Nenana River Valley.

The versions of the PLUVUE I and PLUVUE II visibility models available at the time of the analysis contained errors that made the optical calculations unreliable for sight paths close to the plume centerline or for times when the sun was close to the horizon. These problems were avoided by using part of the PLUVUE I model to calculate the concentrations of species in the plume and then performing separate optical calculations. The PLUVUE I model assumes a Gaussian plume cross section without accounting for the effects of terrain features on plume transport or diffusion.

Specifically, the calculations used the plume rise, plume transport, plume diffusion, and plume chemistry modules in PLUVUE I, but did not use the optical module.

Data used in the modeling were on-site air quality and meteorological data collected from September 1990 through August 1991. The modeling was performed for all daytime hours (hours that the sun was above the horizon halfway through the hour) with wind directions within 15 degrees of a straight line that would transport the plume to the Visitor Access Center and with wind speeds less than 15 mph (as measured at a monitoring station 0.8 km west of the HCCP site at 30 m above ground level). A total of 372 hours satisfied these criteria. Other hours were excluded because a perceptible plume would not be expected at the Visitor Access Center under other conditions. The range of wind directions was selected to allow transport of the plume to the Nenana River Valley and the Visitor Access Center. The wind speed threshold was introduced to prevent calculations for hours when wind speed would dilute the plume enough so that there could be no perceptible effects. However, only 1 hour was eliminated by this criterion. The modeling used the Pasquill atmospheric stability classes calculated from the meteorological data.[5]

Screening results indicated that almost all of the potential visibility impacts would be caused by NO_x emissions. As the NO_x emissions exit the stack, they would primarily be in the form of nitric oxide (NO), a colorless gas. Therefore, a visible NO_2 plume is not expected at the stack. However, NO is rapidly oxidized by natural ozone (O_3) in the atmosphere to form NO_2, a reddish-brown gas. When looking through a sufficiently long segment of an NO_2 plume, the plume would be visible as a yellow or brown ribbon. The visual effects of particles in the plume, including sulfate particles formed from SO_2, were considered and it was found that in almost all cases, any reasonable concentration of particles in the emissions would counteract and diminish the visual effects of NO_2 and cause the plume to be less visible because particles scatter light to effectively brighten the plume. For most viewing conditions, omitting the effects of particles causes the visibility impacts of the HCCP emissions to be overestimated. Therefore, additional modeling was limited to evaluating the effects of NO_x emissions.

Optical effects of a plume depend on the burdens of light-absorbing and light-scattering materials in the sight paths through the plume. For the optical calculations, NO_2 burdens were calculated for oblique (sloping) sight paths through the plume as seen by an observer at the Visitor Access Center who is directly under the plume centerline. The observer looks toward the HCCP site for the north sight path and away from the HCCP site for the south sight path. Burdens were obtained by integrating the NO_2 concentrations in the plume predicted by PLUVUE I along each sight path. Burdens typically are given in units of ppbv·km, the multiplicative product of (1) concentration in parts per billion by volume and (2) distance in kilometers. Calculations for a slice through the plume were performed first, and these results were then used to select cases for more detailed analysis.

NO_2 plume burden profiles were calculated for each of the 372 hours for which PLUVUE I model results were available. The view elevation angles ranged from zero degrees (horizontal sight path) to 20 degrees above the horizontal in steps of 0.2 degrees. Thus, for each hour that was modeled, calculations were done for 100 view elevation angles directly under or through the plume centerline for both the north and south sight paths. For views to the north, the sight paths ended 6 km downwind from the source, which is 7.5 km from the observer. For views to the south, the sight paths ended 28 km downwind from the source, which is 14.5 km from the observer. Note that neither

PLUVUE I nor PLUVUE II is capable of ending sight paths at a fixed distance from the observer, as is required for these calculations.

The NO_2 plume burdens were determined by calculating the NO_2 concentrations at 10-m steps along the sight path, adding the results, and multiplying by 10 m. Thus, 750 plume concentration calculations were performed for each view elevation angle for the north sight path, resulting in 75,000 calculations for all 100 angles for each hour modeled. Likewise, 1,450 plume concentration calculations were performed for each angle for the south sight path, resulting in 145,000 calculations. Performing these calculations in such a way that each concentration was the same as would have been obtained from PLUVUE I was complicated by the fact that PLUVUE I calculates the plume dispersion differently for each of three mixing conditions described below:

1) If the plume centerline is above the top of the mixed layer, plume dispersion is determined from the Gaussian dispersion formula that includes the reflection of the plume from the earth's surface, but ignores the top of the mixed layer as if the plume were in a mixed layer of unlimited height.

2) If the plume centerline is below the top of the mixed layer and the centerline concentration is less than the concentration that would be produced by uniform vertical mixing and Gaussian horizontal dispersion, then it is assumed that the plume is uniformly mixed in the vertical. For this mixing condition, the PLUVUE I results give the same concentrations at the plume centerline and at the surface under the plume centerline.

3) If the plume centerline is below the top of the mixed layer and the requirements for the second mixing condition are not satisfied, plume dispersion is determined from the Gaussian dispersion formula that includes reflection of the plume from both the surface and the top of the mixed layer. Note that if the top of the mixed layer is very high, then the plume does not mix to that height and the limitation on the upward mixing has no practical effect.

It was possible to determine which calculation method was used by PLUVUE I by determining whether the plume centerline was above the top of the mixed layer, and whether the plume centerline and surface concentrations were equal. For the sight path to the north, the second test was performed on the concentrations calculated by PLUVUE I at a downwind distance of 10 km and the results were assumed to apply to the entire sight path. For the south sight path, the second test was performed on the concentrations calculated by PLUVUE I at a downwind distance of 21 km. The uncertainties introduced by this assumption are believed to be minor.

The Gaussian dispersion formula contains the factor $Q/2\pi u$, where Q is the emission rate of the chemical species, such as NO_x, in units of mass per time and u is the wind velocity. For an inert species, this factor does not depend on the downwind distance. The concentrations of the chemical species at any location in space can be calculated from the Gaussian dispersion formula if the value of this factor, the plume dispersion parameters σ_y and σ_z, and the height of the plume centerline are known.

The procedure used for calculation of the NO_x concentration at each 10-m interval along the sight paths was as follows:

1) For each hour modeled by PLUVUE I, the value of $Q/2\pi u$ was calculated from the plume centerline NO_x concentration and from the downwind values of σ_y and σ_z which were calculated by PLUVUE I. For the north sight path, the values 10 km downwind were used; for the south sight path, the values 21 km downwind were used.

2) The PLUVUE I data were tested to see which of the three dispersion calculation methods were used.

3) Then for any location along any oblique sight path, the NO_x concentration was calculated from the value of $Q/2\pi u$ determined for that hour, from the values of the plume dispersion parameters σ_y and σ_z determined from the stability class and the downwind distance of that location using the same subroutines as used by PLUVUE I, and from the dispersion formulas appropriate for the dispersion calculation method used by PLUVUE I.

The NO_2 concentration was then determined from the calculated NO_x concentration and the background O_3 concentration as measured at a monitoring station near the DNPP Visitor Access Center. In these calculations, the photolysis of NO_2 by daylight was neglected, so the calculated NO_2 concentrations were slightly higher than they would have been if the photolysis rates had been considered in the calculations. The NO_2 concentrations were then added for each step in the sight path and multiplied by 10 m to obtain the NO_2 burden.

The resulting profiles were sorted according to the maximum burden in the profile, and the oblique sight path generating the maximum NO_2 burden was used for each hour. The six cases with the highest burdens are illustrated in Figure 2. This figure shows only the data for the lowest 10 degrees of the 20 degree range of elevation angles for which calculations were performed. Above 10 degrees, the burdens always decreased steadily toward zero.

White et al. found that the optical effects of the plume were described at least as well by these alternate calculations as they were by any of the plume visibility models, including PLUVUE I.[6] In general, the alternate calculations tend to predict greater effects than actually would be measured.[6]

The calculated burdens were compared with plume perceptibility to derive a perception threshold for the visibility analysis. Laboratory data that provide the technical basis for the EPA guidance on the threshold contrast for the visual perception of plumes indicate that the threshold depends on the angular subtense of the plume.[7] Therefore, the analysis included the calculation of the angular subtense of the plumes generated by PLUVUE I. Because the view was approximately along the plume axis, the plumes viewed from the Visitor Access Center always subtended an angle greater than 4 degrees. Therefore, this plume width was used as a reasonable lower limit.

A review of the EPA guidance on the threshold contrast found that it was based on perception thresholds for sine-wave patterns with 5 full cycles. However, plumes appear more as a one-cycle sine-wave pattern than a five-cycle pattern. Data for sine-wave patterns with only 1 cycle, available in the same guidance, indicated that the perception thresholds were typically a factor of 2 greater than corresponding thresholds for 5 full cycles.[7] The dashed curve in Figure 3 shows an increase of a factor of 1.7 in the perception threshold, which is one of the smaller increases reported. Therefore, the analysis used the dashed curve to determine that the threshold contrast for a plume with an angular subtense of 4 degrees is slightly greater than 0.04.

estimates are greater than for the HCCP alone, the number of hours is still small for the base case: 8 hours for the north sight path, 13 hours for the south sight path, and a total of 15 hours. Again, the percentage of hours affected is much less than 1% of daytime hours during the year. The sensitivity analysis displays increases similar to those for the HCCP alone.

Table 1 also displays the results for Unit No. 1 alone. The columns in Table 1 do not tally because the modeling was performed separately for each emission source and the combination of the two emission sources. For the base case, the analysis predicts a perceptible plume from Unit No. 1 alone for 5 hours for each of the north and south sight paths, and a total of 6 hours. For the sensitivity analysis, a perceptible plume is predicted a total of 17 hours for the extended sight path, 42 hours for the 69 ppbv·km threshold, and 145 hours for both the extended sight path and the 69 ppbv·km threshold. However, there have been no published sightings from or within the park of a visible NO_2 plume from Unit No. 1, suggesting that the park is not currently experiencing a visibility problem of concern to the park service or its visitors caused by Unit No. 1. As further evidence, time-lapse cameras operating within and adjacent to DNPP from January 1992 through April 1993 did not detect any NO_2 plumes in the Nenana River Valley. Therefore, the base case visibility analysis provides an upper-bound estimate of actual visibility impacts from Unit No. 1 and similarly is expected to form an upper-bound estimate of impacts during the simultaneous operation of Unit No. 1 and the HCCP. The sensitivity analysis indicates that extending the sight path or using a 69 ppbv·km threshold is overly conservative in this visibility analysis. However, it should be noted that some of the overall conservativeness may be due to other conservative assumptions made in the visibility analysis (e.g., ignoring the photolysis of NO_2 by daylight). The portion attributable to extending the sight path and/or using a 69 ppbv·km threshold is unknown.

CONCLUSIONS

The methodology developed in this visibility analysis should be useful for cases in which the optical calculations in the PLUVUE I and PLUVUE II models are unreliable because the sight paths are close to the plume centerline or for times when the sun is close to the horizon, as often occurs at high latitudes during winter. For this analysis, a perceptibility threshold corresponding to an NO_2 burden of 150 ppbv·km appears justified because observers would be positioned within or near the plume, causing the plume to be more difficult to distinguish because it would cover a viewing angle of greater than 4 degrees. This analysis took advantage of the existing Healy Unit No. 1 by comparing the predicted number of hours for a perceptible plume with actual experience by observers and camera monitoring equipment. A sensitivity analysis indicated that extending the sight paths or using a 69 ppbv·km threshold would be overly conservative in this case, perhaps due in part to other conservative assumptions made in the visibility analysis.

These findings have implications for other visibility analyses. Specifically, these results indicate that it would be unwise to reject a permit application on the basis of visibility modeling using this methodology, performed for a similar source in a similar setting, which indicated a few hours per year in which the perception thresholds were exceeded by modest amounts.

While using PLUVUE I and PLUVUE II in the analysis, it became apparent that PLUVUE II would benefit from several refinements. Some of the refinements have been implemented for EPA, and a publication describing the refinements and the present status of PLUVUE II is in preparation.[8]

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5. Pasquill, F., "The Estimation of the Dispersion of Windborne Materials," *Meteorol. Mag.*, **90**, (1063): 33-49 (1961).
6. W. H. White et al., "Predicting the Visibility of Chimney Plumes: An Intercomparison of Four Models with Observations at a Well-controlled Power Plant," *Atmos. Env.* **19**, 515–28 (1985).
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8. L. W. Richards and J. Touma, in preparation.

Table 1. The number of daytime hours during the year that a plume from Unit No. 1 and the Healy Clean Coal Project (HCCP) is predicted to be perceptible.

North sight path				South sight path				Total[1]			
Base case	Extended sight path	Threshold of 69 ppbv·km	Change in both parameters	Base case	Extended sight path	Threshold of 69 ppbv·km	Change in both parameters	Base case	Extended sight path	Threshold of 69 ppbv·km	Change in both parameters
HCCP											
2	2	2	77	2	4	13	20	2	4	14	78
Unit No. 1											
5	13	42	143	5	9	29	46	6	17	42	145
Unit No. 1 plus HCCP[2]											
8	42	52	259	13	20	47	60	15	53	57	262

[1]The total is less than the sum of the north and south sight paths because of some hours in which the threshold was simultaneously exceeded in both sight paths.
[2]Based on modeling the NO_2 emissions from both sources rather than summing the previous two lines (the columns do not add up because the modeling was performed separately for each emission source and the combination of the two emission sources).

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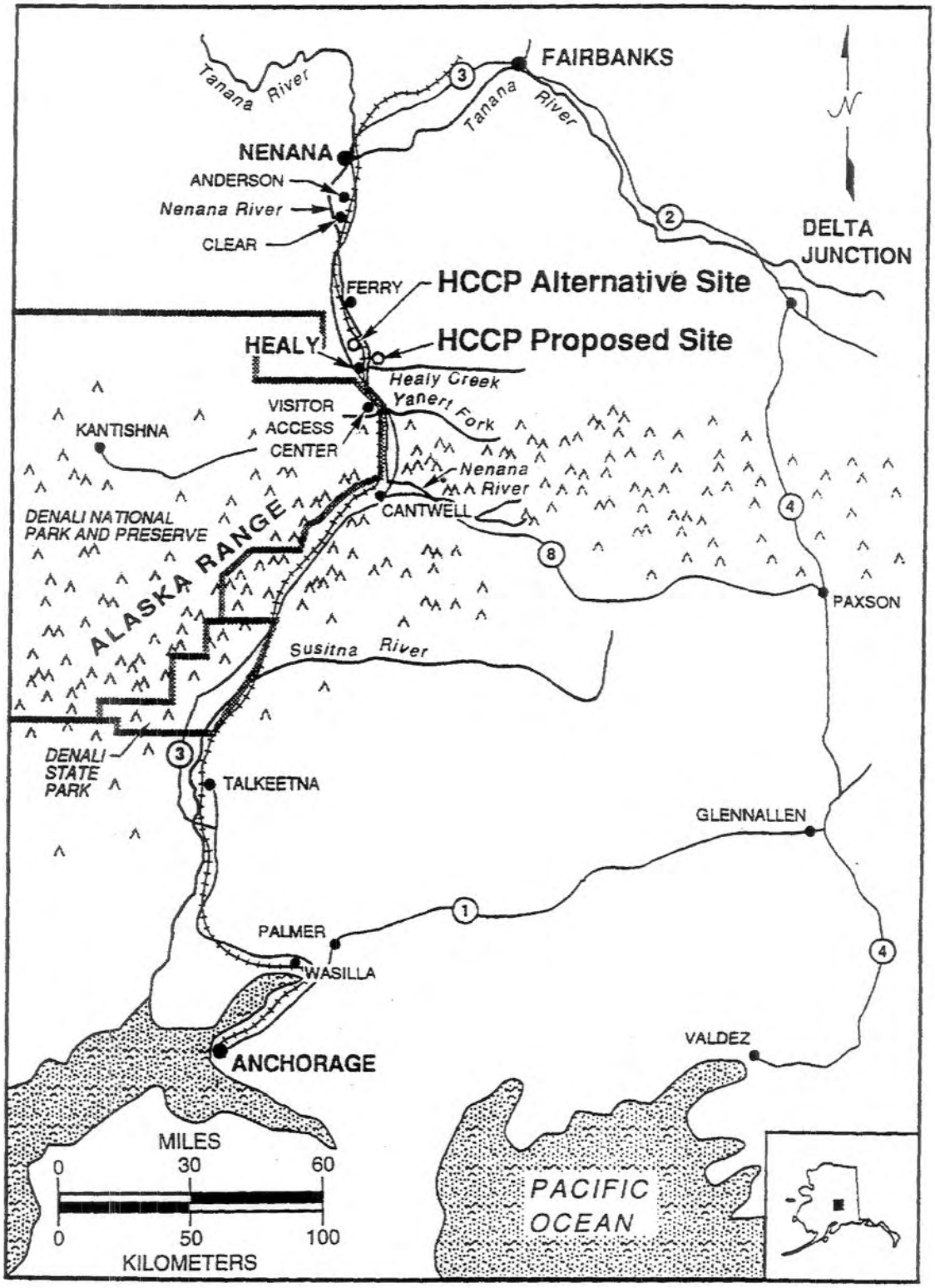

Figure 1. Location of the proposed Healy Clean Coal Project.

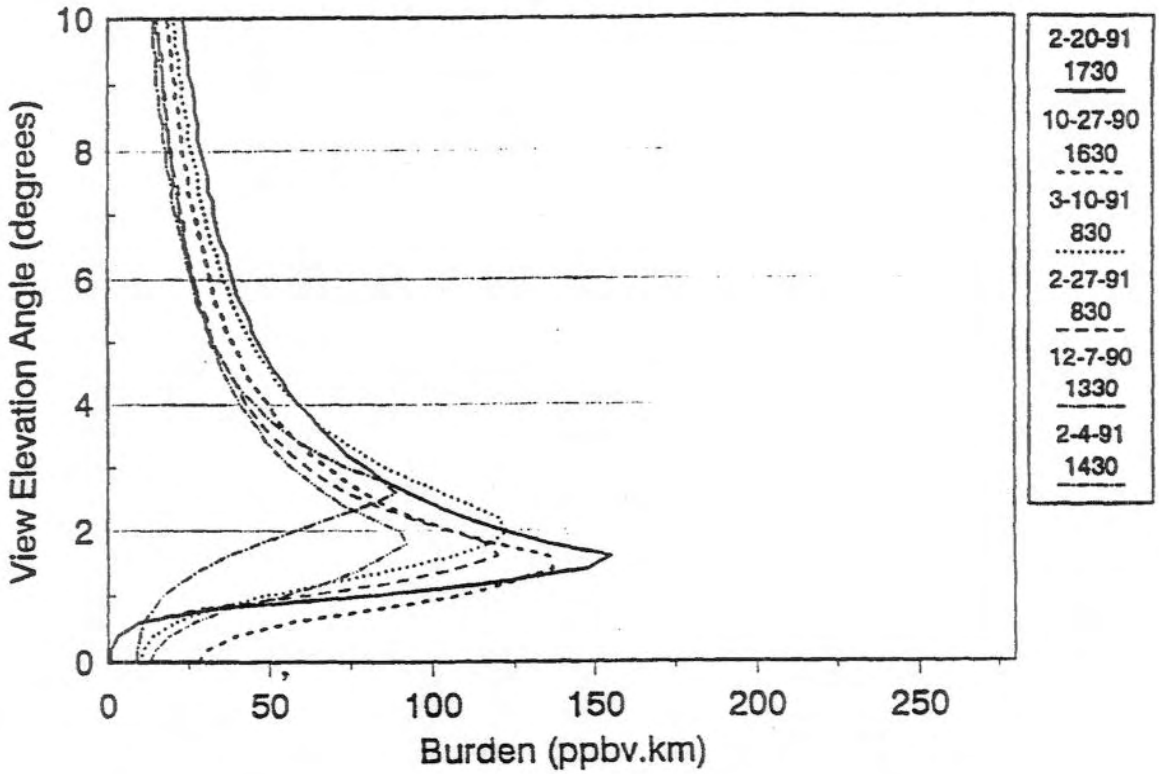

Figure 2. Calculated NO_2 burden as a function of view elevation angle for the sight path north from the DNPP Visitor Access Center. Curves for the six hours with the highest calculated NO_2 burdens due to the emissions are shown.

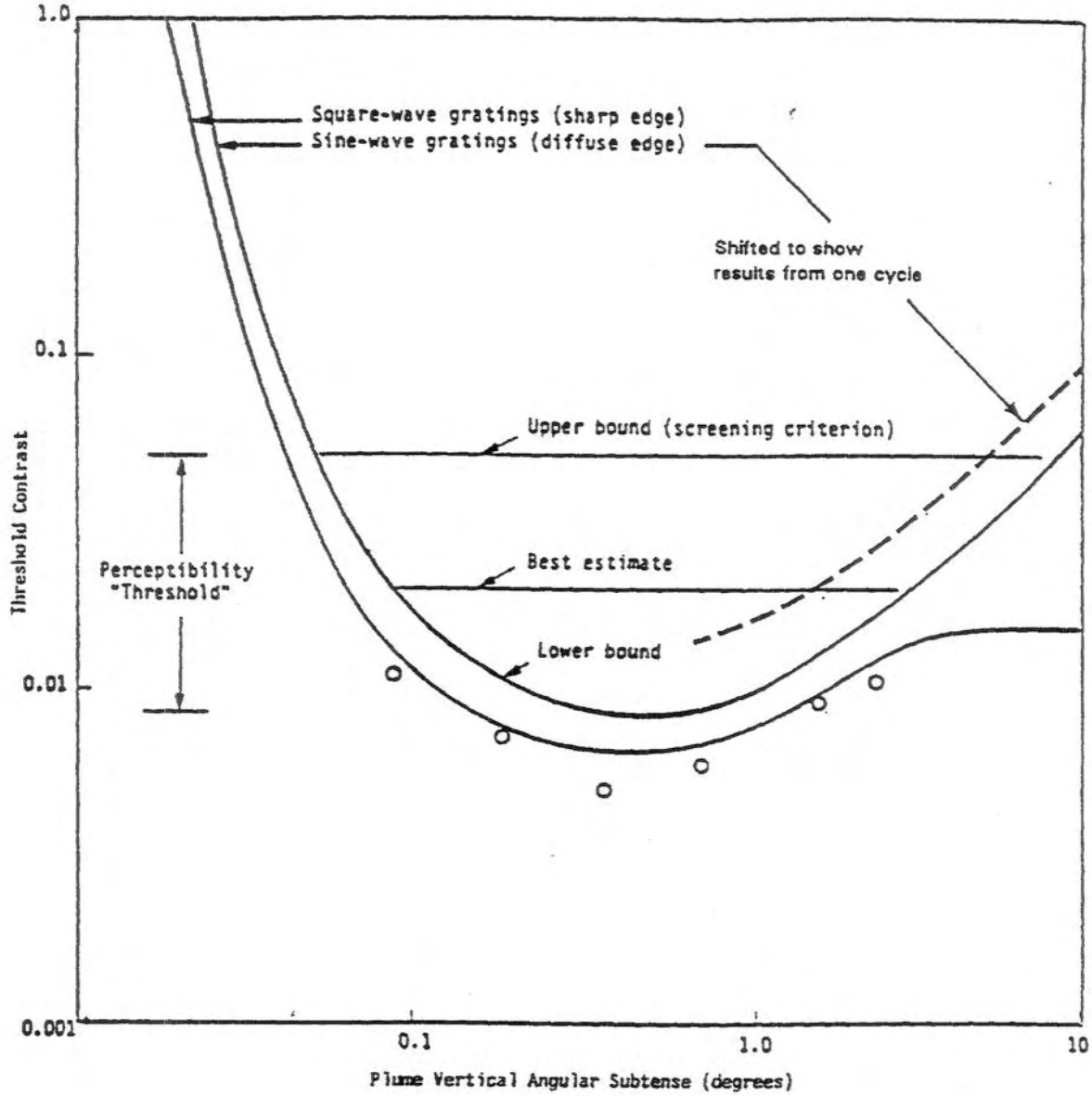

Figure 3. The dashed line shows the adjustment in the EPA guidance that would result if the contrast threshold was determined for a one-cycle sine-wave pattern.

Appendix J

Discussion of Acid Neutralizing Capacity Analysis for Shenandoah

Screening Acid Neutralizing Capacity Analysis for Shenandoah NP: Impacts of the Proposed Warren County Combined-Cycle Project

Introduction

Results of the nitrogen deposition analysis using AERMOD for the proposed Warren County Combined-Cycle Project ("Project") indicate that certain nearby areas within Shenandoah National Park modeled within 50 km to the south of the project site could have an annual deposition of more than the screening Deposition Analysis Threshold (DAT) of 0.01 kg/(ha-yr). In previous Prevention of Significant Deterioration (PSD) projects[1] reviewed by the Federal Land Managers with areas of predicted deposition impacts above the DAT, AECOM provided additional analyses in the form of Acid Neutralizing Capacity (ANC) to address concerns about specific impacts to watersheds. A conservative screening analysis that addresses acidic deposition in 9 watersheds identified by the National Park Service[2] in their 2006 study of the Shenandoah National Park within 50 km of the Project site is described below.

Acid Neutralizing Capacity Assessment Procedure

The United States Department of Agriculture (USDA) Forest Service has provided guidance[3] for a screening procedure to calculate the change in watershed ANC from a baseline value established for selected watersheds that could possibly be affected by a proposed project.

The threshold values for change in ANC (expressed in microequivalents per liter, or µeq/l) that would not cause an adverse impact on the identified resource are as follows:

- If the baseline ANC is greater than 25 µeq/l, up to a 10% change in ANC is allowed.
- If the baseline ANC is between 0 and 25 µeq/l, up to a 1 µeq/l change in ANC is allowed.
- If the baseline ANC is less than 0, "no change" in ANC is allowed (impacts must be mitigated).

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[1] See, for example, Section 6.6.4 and Appendix H of the Desert Rock Energy Project modeling protocol in document EPA-R09-OAR-2007-1110-0012 at http://www.regulations.gov/search/Regs/home.html#docketDetail?R=EPA-R09-OAR-2007-1110.

[2] Cosby, B.J., J.R. Webb, J.N. Galloway, and F. A. Deviney, 2006. Acidic Deposition Impacts on Natural Resources in Shenandoah National Park. Technical Report NPS/NER/NRTR—2006/066. Available at http://www.nps.gov/nero/science/FINAL/SHEN_acid_dep/SHEN_acid_dep.htm.

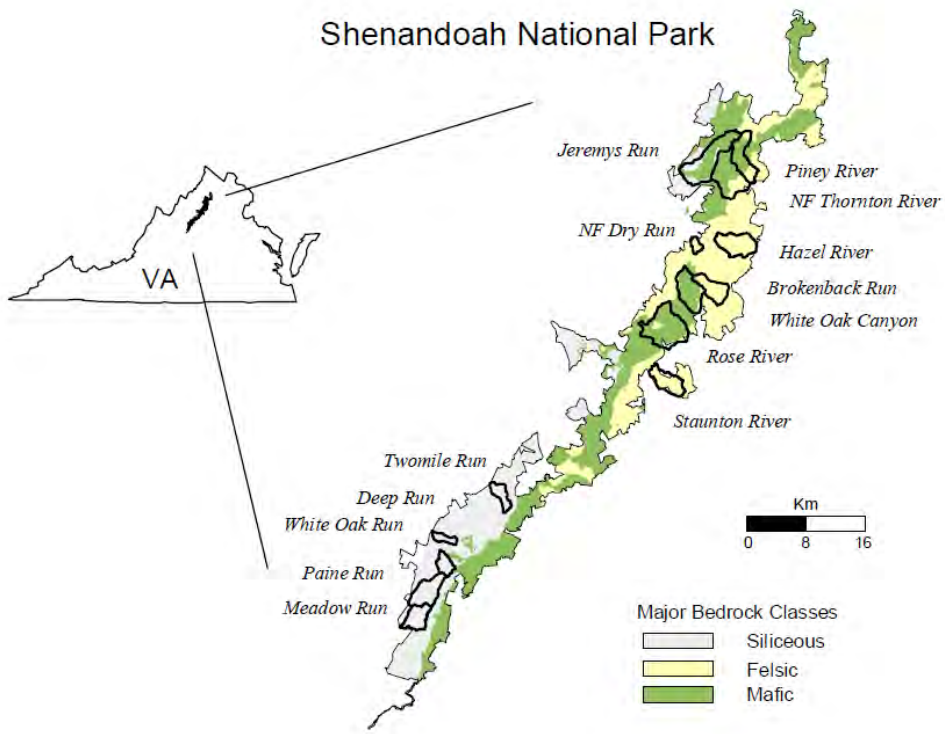
[3] USDA Forest Service Rocky Mountain Region. January, 2000. Screening Methodology for Calculating ANC Change to High Elevation Lakes. Available at www.fs.fed.us/air/documents/**anc**_scre.pdf.

In the analysis provided below, we show that all of the identified watersheds have a baseline ANC above 25 µeq/l. Therefore, we compute the change in the ANC and show that it is well below a 10% change.

Watershed Areas in Shenandoah National Park Within 50 km of the Project

The National Park Service 2006 study has a 2010 supplemental study[4] that references the 2006 study, but does not provide any information to contradict the findings of the 2006 study. The 2006 study identifies 14 watersheds within the Shenandoah National Park (see Figure 1), of which 9 in the northern portion of the park are within 50 km of the Project and constitute the area with acidic deposition predictions above the DAT. Note that the Project is fired with natural gas, so that sulfur deposition impacts will be minimal.

Figure 1 Primary Watersheds in Shenandoah National Park[5]



[4] Sullivan, T.J., B.J. Cosby, and T.C. McDonnell. 2010. Aquatic Critical Loads and Exceedances in Acid-Sensitive Portions of Virginia and West Virginia. Provided by the National Park Service.

[5] Copied from Figure 1.2 of the 2006 National Park Service study.

The baseline ANC values for the 9 northern watersheds are listed in the middle and bottom portions of Table 1, obtained from the 2006 National Park Service study. Even if the lowest quartile value is used for the worst-case season (winter), the baseline ANC value is above 25 µeq/l for all 9 watersheds.

Table 1 Characteristics of Shenandoah National Park Watersheds[6] for the Worst-Case Season (Winter)

		Percent of Watershed Area			ANC (ueq/L)			SO_4 (ueq/L)			SBC (ueq/L)		
Site ID	Watershed	Siliciclastic	Granitic	Basaltic	25th	median	75th	25th	median	75th	25th	median	75th
Siliciclastic Bedrock Class													
DR01	Deep Run	100	0	0	-0.4	0.3	1.7	105.3	108.9	111.2	133.8	137.4	137.7
PAIN	Paine Run	100	0	0	1.2	2.9	4.4	110.2	113.9	116.1	144.8	149.5	155.3
VT36	Meadow Run	100	0	0	-4.6	-2.4	_0.8	89.4	92.3	101.8	115.3	118.2	124.6
VT53	Twomile Run	100	0	0	4.6	7.8	10.3	100.3	105.7	108.6	141.1	143.9	147.5
WOR1	White Oak Run	100	0	0	13.1	15.3	17.1	74.1	79.6	82.5	132.1	133.9	148.0
Granitic Bedrock Class													
NFDR	North Fork Dry Run	0	100	0	32.4	35.3	44.1	96.8	101.1	110.1	194.4	207.4	225.5
VT58	Brokenback Run	0	93	7	49.4	57.9	65.6	42.7	45.3	51.4	140.7	146.2	156.8
STAN	Staunton River	0	100	0	68.0	71.2	74.4	42.3	47.0	50.0	152.2	153.3	157.4
VT62	Hazel River	0	100	0	59.5	65.8	75.7	39.4	42.5	46.4	152.4	155.6	173.4
Basaltic Bedrock Class													
VT51	Jeremys Run	31	0	69	110.5	120.8	137.8	128.6	133.6	138.6	313.5	320.7	328.3
PINE	Piney River	0	31	69	138.3	145.1	159.3	68.3	71.8	76.2	278.8	296.4	307.8
VT61	North Fork Thornton R.	5	27	68	177.1	190.5	205.8	92.4	95.0	96.6	358.7	364.5	378.0
VT66	Rose River	0	9	91	96.1	102.8	108.0	56.1	58.4	61.3	230.0	231.6	245.3
VT75	White Oak Canyon Run	0	14	86	87.0	89.4	99.6	55.3	59.4	60.6	210.1	212.8	220.3

[a]The data cover 14 water years except for VT75 (11 years).

Project Impact on ANC – Screening Analysis

The project's peak nitrogen deposition impact from the conservative AERMOD modeling is very isolated, but could reach about 0.04 kg/(ha-yr). For purposes of this ANC analysis, we round this value up to 0.05 kg/(ha-yr) to account for a small amount of sulfur acidic deposition and we very conservatively apply this value to the entire area of Shenandoah National Park within 50 km of the Project location.

To obtain the ratio of the project ANC change to the baseline ANC value, the USDA Forest Service guidance involves the following calculation:

% ANC change = [Hdep/ANC(o)] x 100, where:

[6] From Table 5.1b of the 2006 National Park Service Study

ANC(o) = baseline ANC for entire watershed in eq = W x P x (1-Et) x A x (10,000m^2/ha) x (eq/10^6 µeq) x (10^3 liters/m^3)

A = baseline lake sample alkalinity in µeq/l

Hdep = acid deposition in eq = [H(s) + H(n)] x W x 10,000m^2/ha

Hs = sulfur deposition in eq/m^2/yr = Ds (kg/ha/yr) x (ha/10,000m^2) x (1000g/kg) x (eq/16g S)

Hn = nitrogen deposition in eq/m^2/yr = Dn (kg/ha/yr) x ha/10,000m^2) x (1000g/kg) x (eq/14g N)

W = watershed area in ha

P = average annual precipitation in meters

Et = fraction of the annual precipitation lost to evaporation and transpiration (assume Et = .33 unless better information is available)

Ds = sulfur deposition in kg/ha/yr from all sulfur species

Dn = nitrogen deposition in kg/ha/yr from all nitrogen species.

The total deposition in eq/m^2/yr (assuming nitrogen deposition) is 3.6 x 10^{-4}.

The annual precipitation for the Shenandoah National Park is ranges from 100 to 150 centimeters per year[7], so a conservatively low value of 1.0 meter will be used.

A conservatively low value of the baseline ANC of 25 µeq/l is used.

In the calculation of the ratio, the watershed area (W) cancels out, as well as the conversion factor, 10,000m^2/ha.

The % ANC change = [Hdep/ANC(o)] x 100 = 3.6 x 10^{-4}/ (1 x 0.67 x 25/10^3) x 100 = 2.1%.

This value is much less than the allowable change in the ANC of 10%. Therefore, the Project's acidic deposition will not create an adverse impact in watersheds in Shenandoah National Park.

[7] http://www.nps.gov/shen/naturescience/weather.htm.