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Dispersion Modeling of Nitrogen Dioxide (NO_2) and Fine Particulate Matter ($PM_{2.5}$) from Backup Generators at Data Centers in Prineville, Oregon

BY

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A research project report submitted in partial fulfillment
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ABSTRACT

As our society becomes increasingly dependent on digital communication (e.g., social media and email) and computerized storage (e.g., digitized medical records and government documents), tech giants such as Google, Facebook, and Apple are constructing and managing an increasing number of massive Internet data centers. These data centers house a network's most critical systems and are vital to the continuity of daily operations. Requiring as much electricity as a medium size city, data centers rely on complex auxiliary power systems to prevent disruption to service. These backup systems consist of tens of multi-megawatt diesel-powered generators that release combustion byproducts, including over populated areas, and may lead to violations of the National Ambient Air Quality Standards (NAAQS). In this study, AERMOD (American Meteorological Society/ Environmental Protection Agency Regulatory Model) was used to model the dispersion of the criteria pollutants nitrogen dioxide (NO_2) and fine particulate matter ($PM_{2.5}$), from backup generators at the Facebook and Apple data centers in Prineville, Oregon. Two scenarios were considered: 1) routine readiness testing, and 2) a major power outage. Modeled spatial and temporal (seasonal) distribution of the pollutants are discussed, as well as the potential health effects on communities in the proximity of these data centers. Future research will include incorporating health and economic impacts, and consideration of adjusted emissions limits using plant site emission limits (PSEL).

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1.0 INTRODUCTION

Society is becoming increasingly dependent on digital communication and computer storage. In recent years, large investments have been made in massive data centers supporting cloud computing services by companies such as eBay, Facebook, Google ($7.3 Billion in 2013 alone (Fiscal Year Results, 2013)), Microsoft, and Yahoo! (Greenberg et al, 2009). Cloud computing refers to both the applications delivered as services over the Internet and the hardware and software in the data centers that provide those services (Fox et al, 2010). Data centers, or "server farms", thus house a network's most critical systems and are vital to the continuity of daily operations. Many data centers have on the order of tens of thousands or more servers drawing tens of megawatts of power at peak operation (Greenberg et al, 2009). Data centers that power Internet-scale applications consume about 1.3% of the worldwide electricity supply and this fraction is expected to grow to 8% by 2020 (Beloglazov et al, 2011). To prevent disruptions to service, data centers rely on complex auxiliary power systems. These backup systems consist of tens of multi-megawatt diesel-powered generators (manufactured by companies such as Caterpillar, Cummins, Detroit Diesel, and John Deer).

Human exposure to diesel exhaust has been shown to cause a number of adverse health outcomes, including pulmonary and cardiovascular diseases, and cancer (Brook et al. 2010; Dockery et al. 1993; Krewski et al. 2009; Laden et al. 2006; Miller et al. 2007; Pope et al. 1995, 2002, 2004; Pope and Dockery 2006; Chen et al. 2008). The exhaust from diesel generators is a complex mixture of gasses, including nitrogen dioxide (NO_2) and nitrogen oxide (NO) (collectively known as "NO_x"), and particulate matter (PM) (Habert, 2015). The Environmental Protection Agency (EPA) regulates NO_2 and PM, among other pollutants, because of their known health effects. The National Ambient Air Quality Standards (NAAQS) (http://www.epa.gov/air/criteria.html), set by the EPA, for the pollutants of interest in this study, NO_2 and $PM_{2.5}$ (PM with an aerodynamic diameter of 2.5 µm or less), are listed in Table 1; included are the route of formation (directly emitted or formed in the atmosphere), the concentration averaging time, the acceptable threshold, and the form of the regulation.

Table 1: National Ambient Air Quality Standards (NAAQS).

Pollutant	Primary/Secondary	Averaging Time	Level (µg/m^3)	Form
NO_2	primary	1 hour	188	98th percentile of 1 hour daily maximum concentrations, averaged over 3 years
	primary and secondary	Annual	99.64	Annual mean
$PM_{2.5}$	primary	Annual	12	Annual mean, averaged over 3 years
	secondary	Annual	15	Annual mean, averaged over 3 years
	primary and secondary	24 hour	35	98th percentile, averaged over 3 years

To restrict facility emissions from stationary generators, emissions from stationary compression ignition internal combustion engines are regulated under Federal Regulation Title 40 Part 52 Subpart MM. Federally approved rules are established in Air Contaminant Discharge Permits (ACDP) (OAR chapter 340, Division 216), which are issued by the State, and set yearly plant site emission limits (PSEL) (OAR chapter 340, Division 222). Nonetheless, the release of combustion byproducts from backup generators may lead to violations of the NAAQS (Bowman, 2014). This is of particular concern in locations with pollutant levels approaching the NAAQS; and, because of the associated health risks, in locations with multiple data centers near residential areas. The Washington State Department of Ecology has used dispersion modeling to estimate the impacts of emissions from data centers near Quincy, Washington (Ecology, 2010). Similarly, in this work, AERMOD (American Meteorological Society/ Environmental Protection Agency Regulatory Model) will be utilized to model the dispersion of NO_2 and $PM_{2.5}$ from backup generators at data centers in Oregon. The study area, AERMOD and its inputs, and results and implications are discussed in this project report.

2.0 CASE STUDY: PRINEVILLE, OREGON

Prineville is located in central Oregon, with a population of 9,253 (U.S. Census, 2010). Prineville is a desirable place for data centers, due to reliable power and dry climate that allows for an innovative evaporative cooling system. In such systems, cooling is achieved through air-side economisation, where filtered outside air is delivered directly to the servers, and a high pressure misting system provides evaporative cooling and humidification (Brady et al, 2013). Facebook and Apple have data centers located in the town of Prineville, OR (Figure 1). Facebook has twenty-eight 3-MW generators on site, and Apple has fifteen 2 to 3-MW generators.

Data centers may be of concern in Prineville because of already high levels of $PM_{2.5}$ (see Table 2). The data are from the Oregon Department of Environmental Quality (DEQ) monitor in Prineville, OR; in two of the years between 2009 and 2012 the maximum 24-hour average concentration of $PM_{2.5}$ is above the NAAQS threshold; in one of those years the 98th percentile is above the standard. It can be seen that the highest values of $PM_{2.5}$ occurred during winter months. The town is currently holding meetings to discuss mitigation in an effort to prevent achieving non-attainment status for $PM_{2.5}$ (Joshua Smith, personal communication, April 14, 2015).

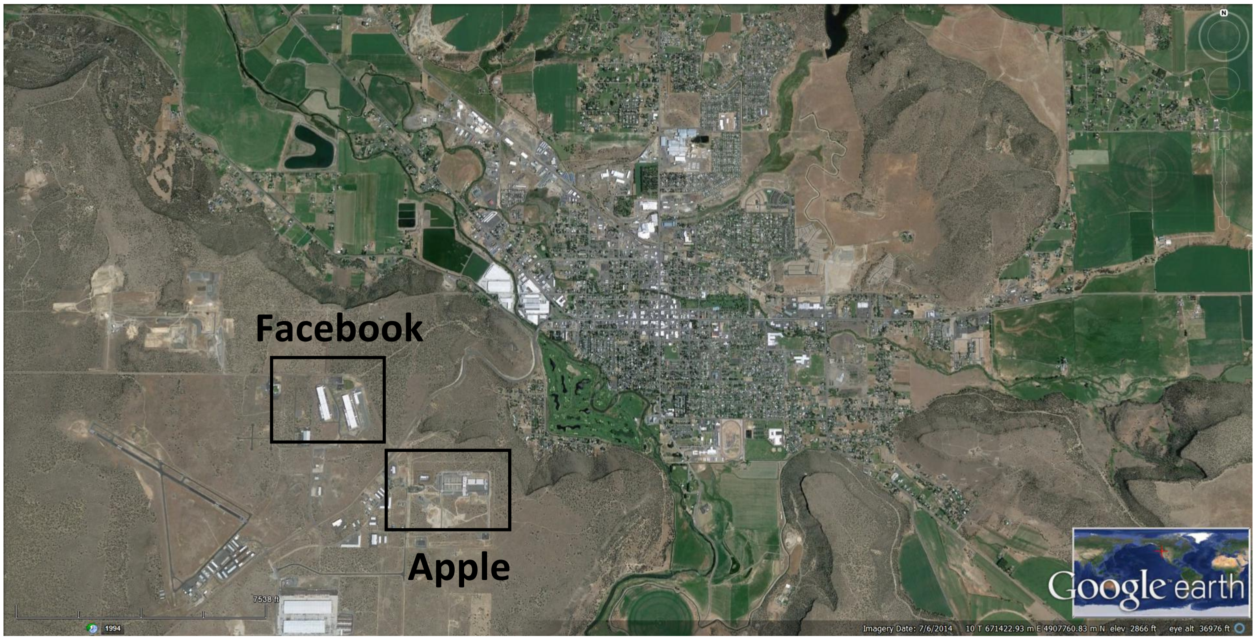

Figure 1: Facebook and Apple data centers in Prineville, Oregon.

Table 2: Average, maximum and 98th percentile $PM_{2.5}$ concentrations from the DEQ monitor in Prineville, OR for four years. NAAQS for 24-hour $PM_{2.5}$ is 35 µg/m^3.

Station Location and Number	Year	Sample Days	Arithmetic Mean	24-hour averages Maximum (date)	24-hour averages 98th Precentile
Prineville	2009	82	9	32 (01/22)	28 (01/10)
Davidson Park	2010	75	7.8	28 (01/02)	28 (12/07)
DEQ #31000	2011	99	9.6	40 (02/02)	37 (12/17)
	2012	119	8.8	37 (11/26)	29 (09/21)

3.0 METHOLODGY

3.1 Model Description and Inputs

AERMOD is the recommended dispersion model from the U.S. EPA, representing the current state-of-science in regulatory modeling. It is a steady-state plume model that incorporates air dispersion based on planetary boundary layer turbulence structure and scaling concepts (http://www.epa.gov/scram001/dispersion_prefrec.htm). The model tracks the dispersion of a pollutant emitted from a source as it travels through space over a defined receptor grid.

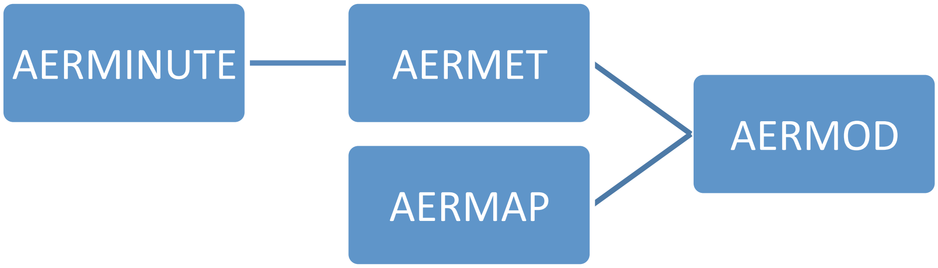

Figure 2: AERMOD model framework with preprocessors: AERMINUTE, AERMET, and AERMAP.

The required inputs for AERMOD are: wind speed and direction, temperature profiles, mixing depth, turbulence parameters, plume characteristics, and degree of urbanization. Before these data are used in AERMOD, meteorological processors are used to format the data (EPA, 2010). Figure 2 depicts AERMOD and the two minimum preprocessors, AERMET and AERMAP, along with an optional preprocessor, AERMINUTE.

AERMET is a meteorological data preprocessor for AERMOD. AERMET uses meteorological data and surface characteristics to calculate boundary layer parameters and creates two output files: a surface data file and a profile data file. (http://www.epa.gov/scram001/metobsdata_procaccprogs.htm). Meteorological data was acquired from National Weather Service (NWS) Integrated Surface Hourly Data (ISHD) format from Redmond's Roberts Field airport (ftp://ftp.ncdc.noaa.gov/pub/data/noaa) and upper air data from National Ocean and Atmospheric Administration/Earth System Research Laboratory (NOAA/ESRL) Radiosonde database (RAOBS) for Salem, OR (http://esrl.noaa.gov/raobs/). Land use of desert scrubland was assumed as the surface characteristics for input to AERMET. Meteorological data from 2013 was used for all simulations.

AERMINUTE, the wind preprocessor is needed for wind speeds that are considered "calm", <1 m/s. Calms are assigned a value of 0 and AERMOD cannot simulate dispersion under missing wind conditions. AERMINUTE processes 1-minute wind data to generate hourly average winds for input to AERMET (http://www.epa.gov/scram001/metobsdata_procaccprogs.htm). Minute wind data was downloaded from NOAA Automated Surface Observing System (ASOS) (ftp://ftp.ncdc.noaa.gov/pub/data/asos-onemin/6405-2013/)

AERMAP is a terrain preprocessor for AERMOD. AERMAP processes gridded terrain data and creates a file suitable for use within an AERMOD control file. This file contains elevation and hill-height scaling factors for each receptor in the air dispersion study, as well as elevations for every source and building (http://www.epa.gov/scram001/7thconf/aermod/aermapugb2.pdf). The Breeze graphical user interface for the AERMOD dispersion model and preprocessors was used in this work (http://www.breeze-software.com/AERMOD/). Terrain data was incorporated using NED files from the National Land Cover Dataset (NLCD) from the US Geological Survey (USGS) (http://www.mrlc.gov/viewerjs/).

Annual facility reports, inspection reports, air contaminant discharge permits, and a testing report were obtained from DEQ through an official records request. These files contained emission factors, hours of operation, emission limits and source parameters (Table 3). Due to lack of facility specific stack height, a stack height of 5 feet above the manufacturer specification height was assumed. This is common practice in modeling for engineering consulting (Monica Wright, personal communication, April 27, 2015). Coordinates of each source were obtained using Google Earth.

Table 3: Generator specifications.

Data center	Size kW	# Generators	Stack height (m)	Stack diameter (m)	Exit Velocity (m/s)	Temperature (K)	NO_x emissions (g/s)	PM emissions (g/s)
Facebook	3490	28	4.82	0.51	43.28	722.59	4.71	0.072
Apple	2750	12	4.91	0.51	43.28	722.59	5.71	0.015
Apple	2000	3	4.06	0.51	43.28	722.59	4.40	0.040

3.2 Model Options

The plume volume molar ratio method (PVMRM) was used to model the conversion of NO to NO_2. Emissions factors are given for NO_x, and not the NAAQS regulated pollutant NO_2. At the emission source, the in-stack ratio is assumed to be 80% NO and 20% NO_2 (San Joaquin Valley Air Pollution Control District, 2010). As the plume travels downwind NO gets oxidized to NO_2. The ultimate ambient equilibrium is assumed to be 10% NO and 90% NO_2 (http://www.epa.gov/ttn/scram/models/aermod/aermod_userguide_addendum_v11059_draft.pdf). In PVMRM, the conversion of NO to NO_2 at a downwind distance from the source is determined by the ratio of the number of moles of ambient ozone that have been entrained into a plume segment at downwind distance to the number of moles of NO_x that have been emitted from the source in the same segment (Hendrick et al, 2013). A background ozone concentration of 50 $\mu g/m^3$ was used, based on information from NW AIRQUEST/Washington State University (http://lar.wsu.edu/nw-airquest/).

EPA's Building Profile Input Program (BPIP) accounts for building downwash (http://www.epa.gov/scram001/userg/relat/bpipd.pdf). Downwash can create higher concentrations near the ground surface and creates turbulence, which alters dispersion. Building heights were obtained from the City of Prineville's Planning Department (Joshua Smith, personal communication, April 14, 2015). For the results shown in this study, BPIP was turned off. Model runs with BPIP will be analyzed in future work.

3.3 Receptors

Simulations were performed using discrete receptors, as well as a receptor grid. The following seven discrete receptors were selected to illustrate spatial variability in modeled concentrations: two near source, four in and around Prineville, and one on an elevated bluff (Figure 3). The UTM coordinates, elevation, and distance to closest generator for each of the seven receptors are listed in Table 4.

Figure 3: Aerial image of discrete receptors, 7 receptors.

Table 4: Discrete receptor description and UTM location.

Description	Eastings (m)	Northings (m)	Elevation (m)	Distance to Closest Source (m)
Near Source SW	668674.7	4905788	933	842
Near Source NE	669747	4907013	987	972
Prineville South	672218.1	4907133	874	2172
Prineville	671689.1	4907721	876	2300

Center				
Prineville North	670678.9	4908594	870	2438
Bluff	673328.7	4905919	996	3187
Prineville NE	672445.4	4908711	895	3410

To further illustrate more detailed spatial variability in modeled concentrations a non-uniform Cartesian grid (Figure 4) was selected. The grid was anchored in the SW corner (668312 m E, 4905541 m N) and expanded NE to cover the data centers and the populous of Prineville. Grid spacing was as follows: 25 meters for the first 2000 meters, 50 meters from 2000 meters to 4000 meters, and 100 meters grid 4000 meters to 8000 meters based on the AERMOD modeling framework applied for Quincy, WA (Ecology, 2010); the grid had a total of 25920 receptors.

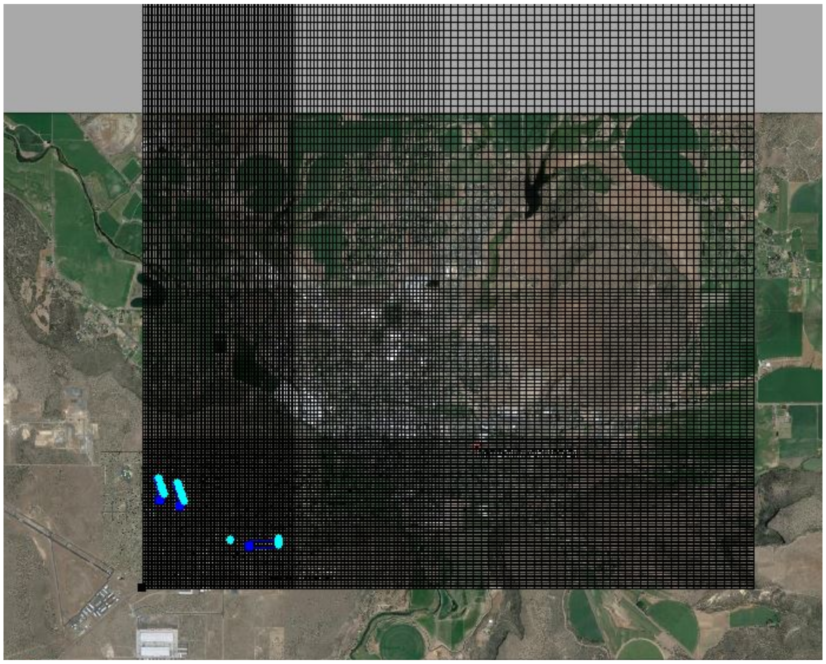

Figure 4: Non-uniform Cartesian receptor grid, 25920 receptors.

3.4 Simulations

Since generators are used for routine testing and to supply power when the commercial source is interrupted, testing and power outage scenarios were represented in the model simulations (Table 5). Monthly testing represents a low emitting scenario (lowest emissions produced), with only one data center testing generators and only one generator running at a time for a duration of one hour. For the annual testing scenarios, both data centers were assumed to operate generators in three groups for a duration of four hours/group, so that all generators were run in a 24-hr period (the duration of one model run). Testing scenarios assumed generators only operate between the hours of 7 am and 7 pm, as testing is often limited to daylight hours (Bowman, 2014). The outage simulations represent a worst-case scenario, with all generators at both data centers operating at the same time for a duration of 20 hours, from midnight to 8 pm. The length of the power outage was chosen based on engine runtime reports in the annual reports from DEQ. Outages, reported on a monthly basis from Facebook in 2012, 2013, and 2014, ranged from 2.09 hours to 48.76 hours.

Table 5: Simulations; run separately for NO_2 and $PM_{2.5}$.

Scenario	Data Center	Total # Gens/day	Duration (hour)	Engines Operating Concurrently	Model Runtime
Monthly Testing	Apple	12	1	1	365 days
Monthly Testing	Apple	12	1	1	Winter
Monthly Testing	Apple	12	1	1	Summer
Annual Testing	Facebook and Apple	43	4	13-15	Winter
Annual Testing	Facebook and Apple	43	4	13-15	Spring
Annual Testing	Facebook and Apple	43	4	13-15	Summer
Annual Testing	Facebook and Apple	43	4	13-15	Autumn
Power Outage	Facebook and Apple	43	20	43	365 days

4.0 RESULTS

The results are organized as follows: 1) 1-hr NO_2 annual testing (gridded receptor and discrete), 2) 1-hr NO_2 outage (gridded receptor and discrete), 3) 24-hr $PM_{2.5}$ annual testing (gridded receptor and discrete), 4) 24-hr $PM_{2.5}$ outage (gridded receptor and discrete), and 5) annual $PM_{2.5}$ annual testing (gridded receptor). No background concentrations are included in the reported predicted concentrations.

4.1 NO_2

The 3D plots of gridded receptor results have a color bar with red corresponding to values over the NAAQS; and yellow, light blue and dark blue corresponding to 90%, 50%, and 25% of the standard, respectively. The maximum hourly NO_2 concentrations for the annual testing simulations are presented in Figures 5 and 6, for winter and summer respectively. The results indicate a winter maximum of 661.28 $\mu g/m^3$ and summer maximum of 641.56 $\mu g/m^3$. For the outage scenario, the maximum hourly concentrations of NO_2 across the receptor grid are presented in Figure 7, with a maximum value of 1389.13 $\mu g/m^3$. The contour plot of the outage scenario, Figure 8, highlights the locations in Prineville with values over the NAAQS threshold for 1-hour NO_2.

The top eight concentrations (winter and summer) at each discrete receptor in the annual testing scenario are listed in Table 6; the results from the power outage scenario are in Table 7. In Tables 6 and 7 the grid cells are color coded by season: blue, green, yellow, and red to indicate winter, spring, summer, and autumn, respectively.

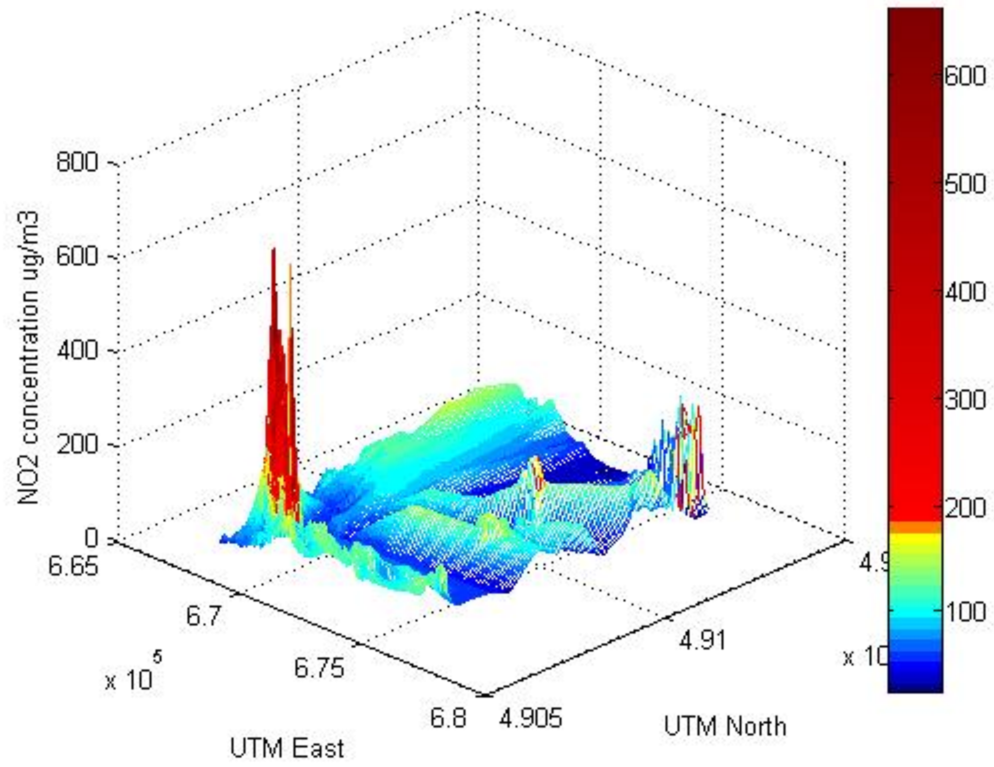

Figure 5: 1st highest 1-hour averaged NO_2 concentrations (µg/m^3) in winter for annual testing scenario, gridded receptors.

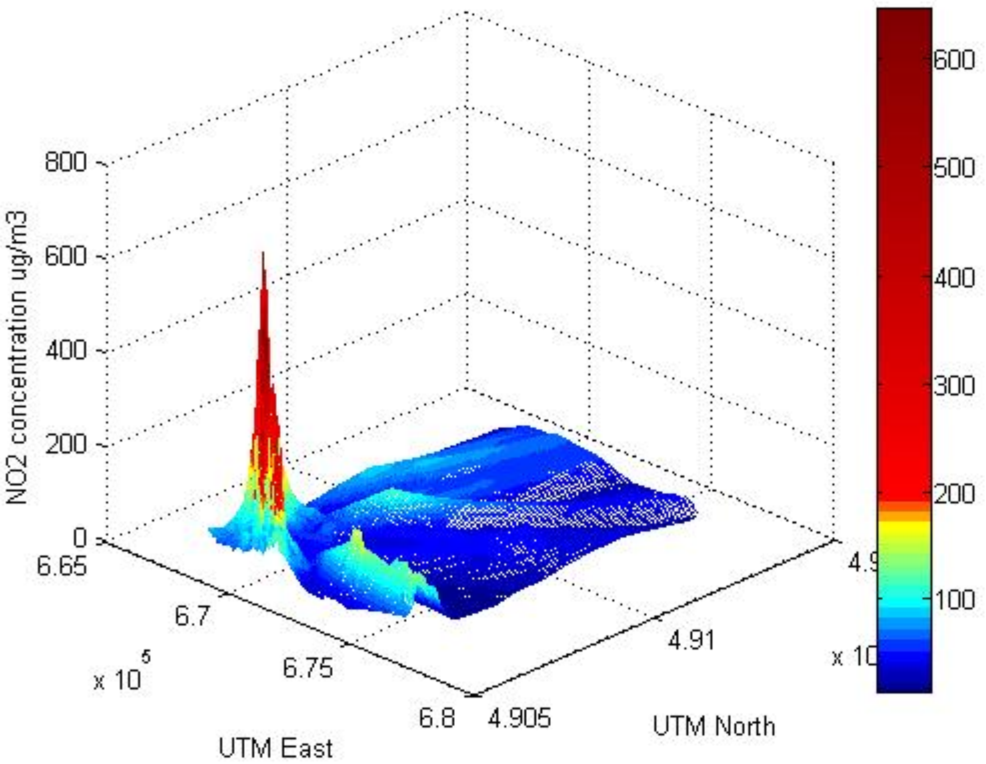

Figure 6: 1st highest 1-hour averaged NO_2 concentrations (µg/m^3) in summer for annual testing scenario, gridded receptors.

Table 6: Comparison of winter and summer 8 highest 1-hour averaged NO_2 concentrations (µg/m^3) for annual testing scenario, discrete receptors.

Receptor	Near NE		Near SW		Center		Prineville South		North		Bluff		NE	
Distance	(842 m)		(972 m)		(2172 m)		(2300 m)		(2438 m)		(3187 m)		(3410 m)	
Season	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
1	58.36	68.80	72.17	80.05	95.67	40.26	65.33	42.13	76.73	105.27	152.81	89.78	40.94	44.38
2	44.86	54.53	70.43	62.95	37.29	28.56	48.02	26.33	56.99	71.55	125.81	30.58	28.36	23.99
3	43.87	34.21	63.08	53.77	35.77	23.25	47.71	25.45	49.58	63.69	100.68	27.30	23.57	23.32
4	41.85	33.25	44.22	47.09	33.61	18.47	34.27	23.28	39.18	50.60	87.25	26.54	22.53	20.50
5	41.82	32.69	42.39	45.11	31.81	16.87	32.24	22.43	38.03	49.01	75.81	24.16	20.02	19.64
6	37.57	32.16	39.78	41.68	28.11	16.85	29.52	19.87	35.96	28.85	47.53	23.08	18.06	18.56
7	34.25	31.24	39.35	41.45	22.73	15.81	27.66	19.61	33.92	24.78	47.22	21.66	16.02	14.24
8	33.32	31.23	38.98	40.79	19.25	15.46	27.57	18.35	31.99	24.58	37.26	19.42	15.40	14.12
Average	41.99	39.77	51.30	51.61	38.03	21.94	39.04	24.68	45.30	52.29	84.29	32.81	23.11	22.34
Median	41.83	32.97	43.30	46.10	32.71	17.67	33.26	22.85	38.60	49.80	81.53	25.35	21.27	20.07
Standard Deviation	7.88	14.08	14.63	13.75	24.12	8.66	13.46	7.60	15.24	27.76	40.89	23.28	8.37	9.62

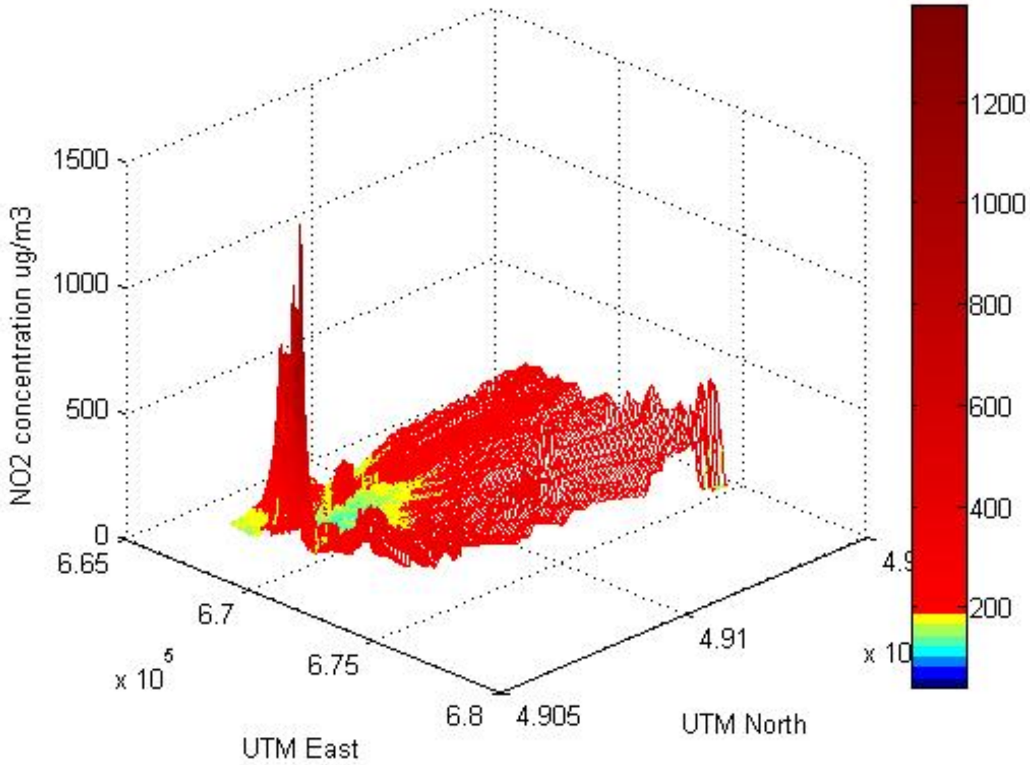

Figure 7: 1st highest 1-hour averaged NO_2 concentrations (µg/m^3) for outage scenario, gridded receptors.

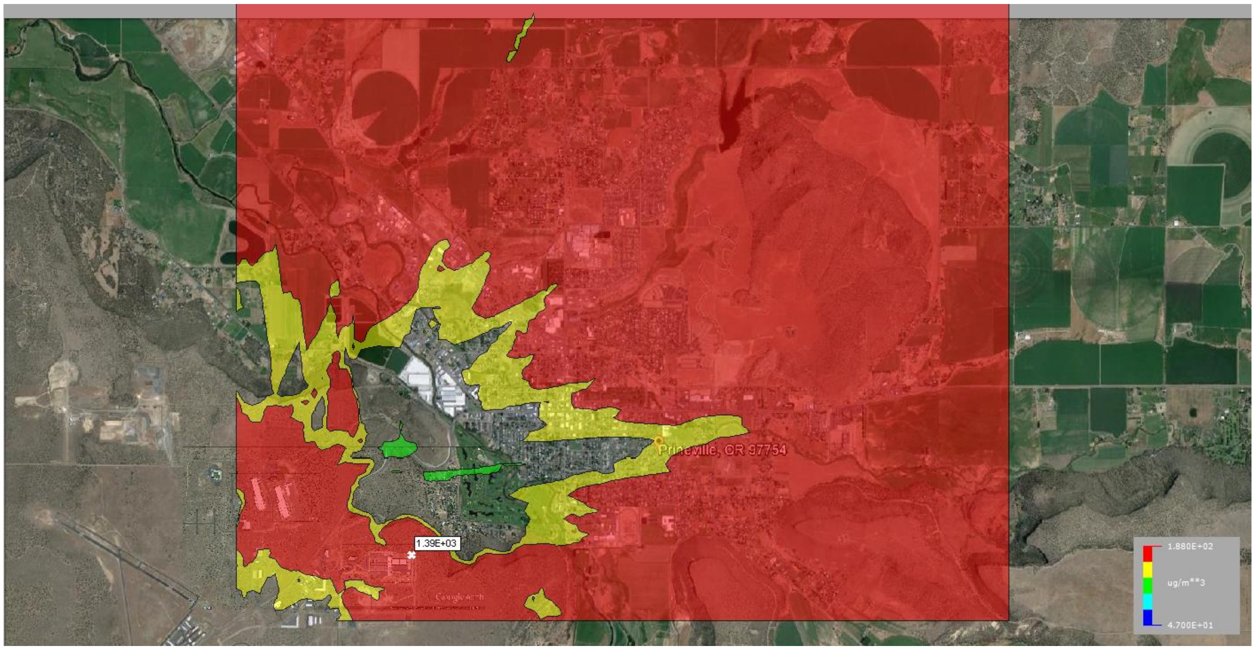

Figure 8: 1st highest 1-hour averaged NO_2 concentrations (µg/m^3) for outage scenario, gridded receptors.

Table 7: 1-hour averaged NO_2 concentrations ($\mu g/m^3$) for outage scenario, gridded receptors.

Receptor	Near NE	Near SW	Prineville Center	Prineville South	Prineville North	Bluff	Prineville NE
Distance	**(842 m)**	**(972 m)**	**(2172 m)**	**(2300 m)**	**(2438 m)**	**(3187 m)**	**(3410 m)**
1	146	158	179	173	177	368	226
2	145	156	161	166	168	358	225
3	138	151	155	161	164	354	223
4	132	151	139	154	162	335	213
5	130	150	121	149	158	326	201
6	126	150	117	146	117	322	180
7	124	150	116	141	114	317	176
8	120	140	105	138	110	307	173

winter **spring** **summer** **fall**

4.2 Primary $PM_{2.5}$

The 3D plots illustrating the gridded receptor results have a color bar with red corresponding to values greater than the computed value of the NAAQS for $PM_{2.5}$ minus a defined model $PM_{2.5}$ background concentration from NW AIRQUEST/Washington State University (http://lar.wsu.edu/nw-airquest/) for Prineville, OR (i.e. 35 $\mu g/m^3$ -31 $\mu g/m^3$); and yellow, light blue and dark blue corresponding with 90%, 50%, and 25% of the computed value, respectively. The maximum 24-hour $PM_{2.5}$ concentrations for the annual testing scenarios are presented in Figures 9 and 10, for winter and summer respectively. The results indicate a winter maximum of 5.12 $\mu g/m^3$ and summer maximum of 20.62 $\mu g/m^3$. The maximum 24-hour $PM_{2.5}$ concentrations for the outage scenario are presented in Figure 11, with a maximum value of 20.60 $\mu g/m^3$. The contour plot of the annual testing scenario, Figure 12, shows the locations in Prineville with annually averaged $PM_{2.5}$ concentrations greater than 0.0033 $\mu g/m^3$ (further discussed in Section 5.0).

The top eight concentrations (winter and summer) for each discrete receptor for the annual testing scenario are listed in Table 8. The results from the outage scenario with the discrete receptor are presented in Table 9, with concentrations color coded by season; blue, green, yellow, red showing winter, spring, summer, autumn, respectively.

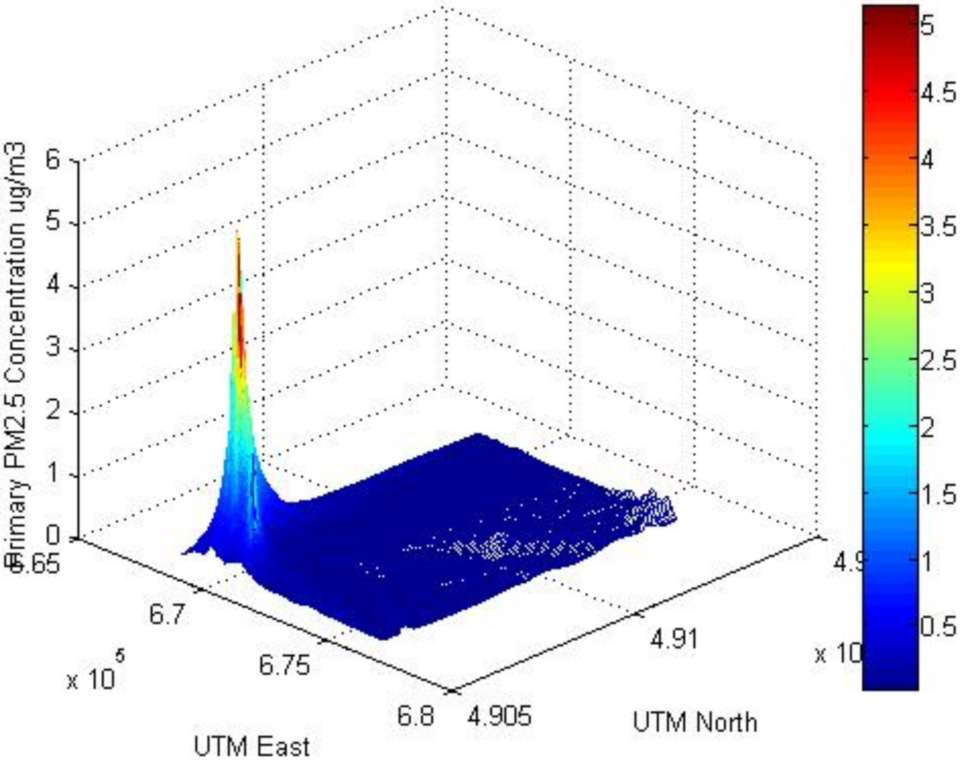

Figure 9: 1st highest 24-hour averaged $PM_{2.5}$ concentrations ($\mu g/m^3$) for winter annual testing scenario, gridded receptors.

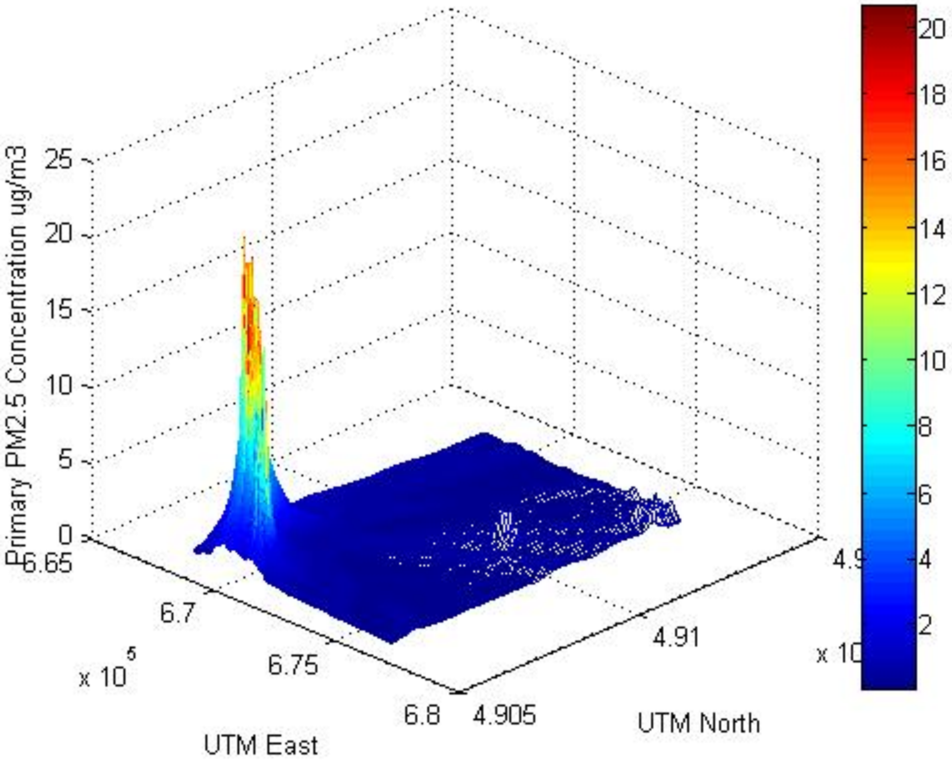

Figure 10: 1st highest 24-hour averaged PM$_{2.5}$ concentrations (µg/m^3) for summer annual testing scenario, gridded receptors.

Table 8: Comparison of winter and summer 8 highest 24-hour averaged PM$_{2.5}$ concentrations (µg/m^3) for annual testing scenario, discrete receptors.

Receptor	Near NE		Near SW		Prineville Center		Prineville South		Prineville North		Bluff		Prineville NE	
Distance	**(842 m)**		**(972 m)**		**(2172 m)**		**(2300 m)**		**(2438 m)**		**(3187 m)**		**(3410 m)**	
Season	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**
1	0.151	1.378	0.360	1.291	0.106	0.284	0.050	0.382	0.069	0.452	0.173	0.508	0.027	0.516
2	0.144	1.179	0.229	0.829	0.058	0.257	0.044	0.274	0.056	0.348	0.089	0.463	0.025	0.326
3	0.139	1.030	0.207	0.768	0.027	0.249	0.035	0.262	0.038	0.310	0.081	0.429	0.016	0.322
4	0.131	0.873	0.185	0.765	0.025	0.180	0.031	0.227	0.037	0.291	0.073	0.403	0.014	0.278
5	0.110	0.699	0.181	0.763	0.024	0.178	0.031	0.220	0.036	0.288	0.049	0.392	0.013	0.260
6	0.073	0.557	0.145	0.762	0.024	0.137	0.026	0.207	0.035	0.219	0.043	0.380	0.012	0.236
7	0.072	0.546	0.129	0.723	0.018	0.133	0.023	0.177	0.025	0.205	0.042	0.361	0.012	0.195
8	0.071	0.476	0.112	0.708	0.017	0.132	0.022	0.152	0.025	0.195	0.036	0.282	0.011	0.190
Average	0.111	0.842	0.194	0.826	0.037	0.194	0.033	0.237	0.040	0.289	0.073	0.402	0.016	0.290
Median	0.120	0.786	0.183	0.764	0.024	0.179	0.031	0.223	0.037	0.290	0.061	0.398	0.013	0.269
Standard Deviation	0.035	0.330	0.078	0.191	0.031	0.061	0.010	0.071	0.015	0.085	0.045	0.068	0.006	0.104

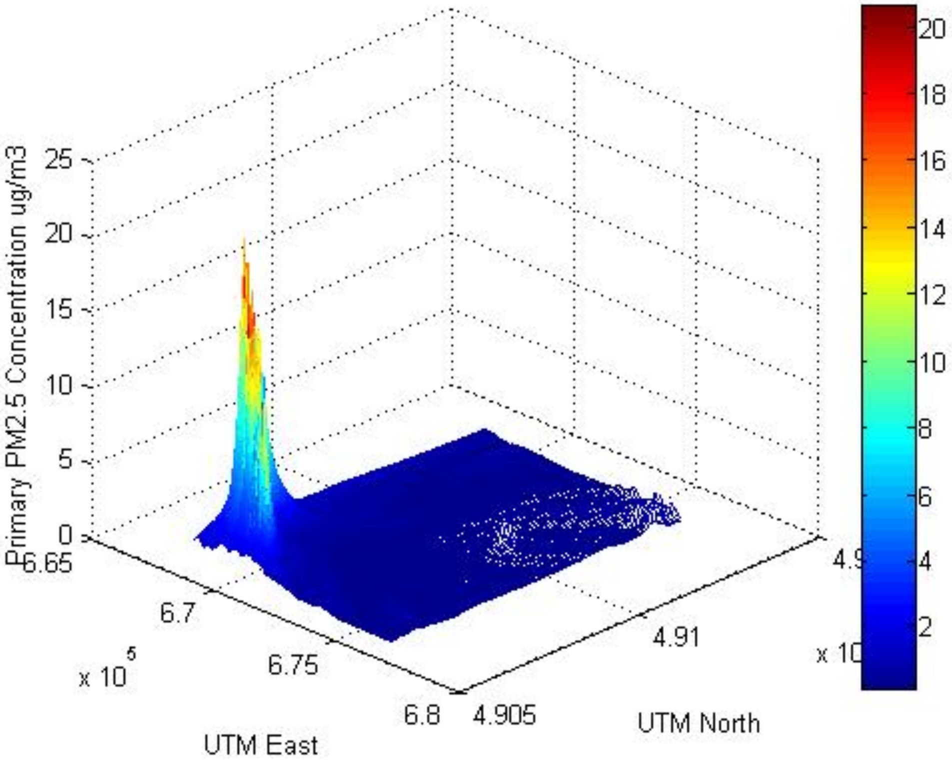

Figure 11: 1st highest 24-hour averaged $PM_{2.5}$ concentrations (µg/m^3) for power outage scenario, gridded receptors.

Table 9: 1st highest 24-hour averaged $PM_{2.5}$ concentrations (µg/m^3) for outage scenario, discrete receptors.

Receptor	**Near NE**	**Near SW**	**Prineville Center**	**Prineville South**	**Prineville North**	**Bluff**	**Prineville NE**
Distance	**(842 m)**	**(972 m)**	**(2172 m)**	**(2300 m)**	**(2438 m)**	**(3187 m)**	**(3410 m)**
1	🟦 0.365	🟩 1.336	🟦 0.446	🟦 0.293	🟦 0.593	🟩 0.393	🟧 2.005
2	🟧 0.274	🟧 0.984	🟧 0.428	🟦 0.279	🟨 0.513	🟦 0.357	🟦 1.597
3	🟧 0.252	🟦 0.878	🟦 0.299	🟨 0.256	🟦 0.429	🟧 0.321	🟩 1.038
4	🟩 0.203	🟩 0.848	🟩 0.294	🟧 0.242	🟧 0.423	🟦 0.285	🟩 1.007
5	🟩 0.189	🟨 0.703	🟦 0.274	🟧 0.227	🟩 0.412	🟦 0.260	🟨 0.988
6	🟦 0.187	🟨 0.619	🟩 0.254	🟧 0.204	🟩 0.390	🟦 0.259	🟨 0.885
7	🟦 0.179	🟩 0.538	🟧 0.223	🟧 0.201	🟦 0.379	🟨 0.245	🟧 0.832
8	🟩 0.178	🟨 0.516	🟨 0.214	🟩 0.182	🟦 0.340	🟧 0.224	🟨 0.831

🟦 **winter**	🟩 **spring**	🟨 **summer**	🟧 **fall**

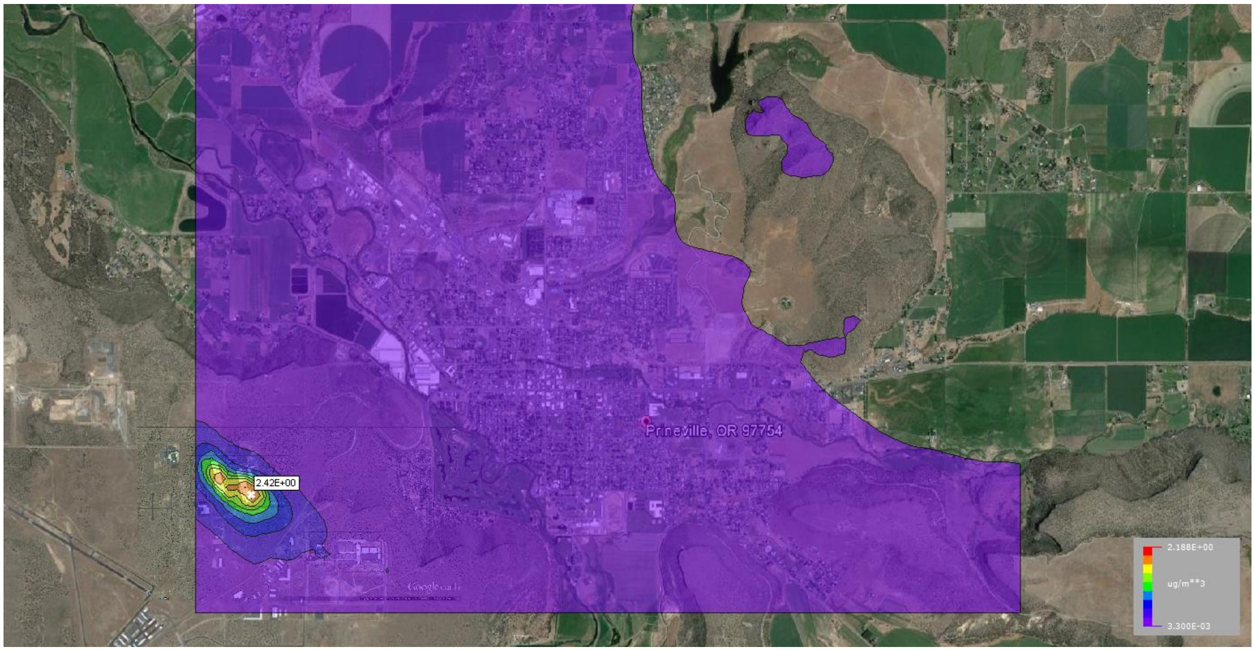

Figure 12: Contour plot of $PM_{2.5}$ concentrations (µg/m^3) for annual testing scenario, gridded receptor. Purple shading indicates concentrations above 0.0033 µg/m^3.

5.0 DISCUSSION AND CONCLUSIONS

Results show concentrations above NAAQS threshold at several time periods and locations for 1-hr NO_2. From the gridded outage scenario, the 1st highest concentration was over the NAAQS threshold at 71% of the receptors, the 8th highest concentration violated the standard at 31% of the receptors. From the gridded annual testing scenario, during summer months the 1st highest concentration was over the NAAQS threshold at 492 receptors (2%) and the 8th highest concentration violated the NAAQS for 123 receptors (0.5%); during winter months the 1st highest concentration was over the NAAQS threshold at 704 receptors (3%) and the 8th highest concentration violated the NAAQS at 57 receptors (0.2%). While the modeled $PM_{2.5}$ concentrations did not exceed the NAAQS, there may still be concern. From a study by Vermeulen et al (2014), which used elemental carbon (EC) as a marker for diesel engine exhaust (DEE); environmental exposure of average EC concentrations of 0.0033 $\mu g/m^3$ resulted in an estimated excess lifetime risk of 1 additional lung cancer death per 1,000,000 individuals as compared to an unexposed population. Results from the gridded annual testing scenario indicated concentrations for annually averaged $PM_{2.5}$ over 0.0033 $\mu g/m^3$ at 93% of the receptors.

The comparison of winter and summer concentrations for the annual testing scenario indicate a pattern of higher concentrations for $PM_{2.5}$ in the summer (Table 8), but no observable seasonal pattern for NO_2 (Table 6). This could be partially due to the averaging times, since $PM_{2.5}$ is averaged over 24 hours and NO_2 over 1 hour. Meteorology could also have an effect on seasonality of concentrations. Wind roses were made from 2013 Prineville hourly wind data (Figure 12) to look for differences/similarities in winter and summer wind patterns. There was a stronger diurnal pattern and more variability in winter winds; in summer the highest percentage of wind was blown toward the north and stronger winds were blown towards north/northwest. Therefore, during summer wind blows pollutants toward Prineville more often than during winter. To look for further patterns in predicted concentrations, the 8 highest 1-hr NO_2 concentrations at the discrete receptors (outage scenario) were plotted against time of day. Figure 13 shows a u-shaped pattern of higher concentrations in the morning and evening, with no highs occurring between the hours of 9 am to 5 pm. The morning and evening timeframe corresponds with lower wind speeds and also a lower planetary boundary layer (PBL) height (Zhang et al, 2014). Temperature, which impacts the height of the PBL, may also play an important role in when the highest concentrations are occurring. Further analysis would be required to determine how each factor (PBL, winds, and temperature) contributes to the observed lower daytime concentrations. Elevation could also have an effect on concentrations; from the discrete receptor results, generally higher concentrations of both $PM_{2.5}$ and NO_2 were predicted at the bluff receptor (the highest elevation).

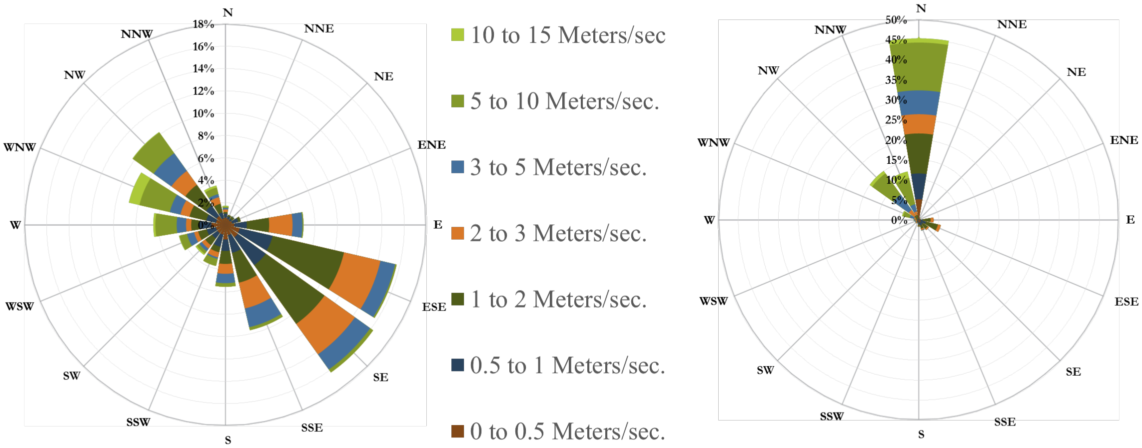

Figure 13: Wind roses for 2013 hourly wind data for Prineville, OR; winter (left) and summer (right).

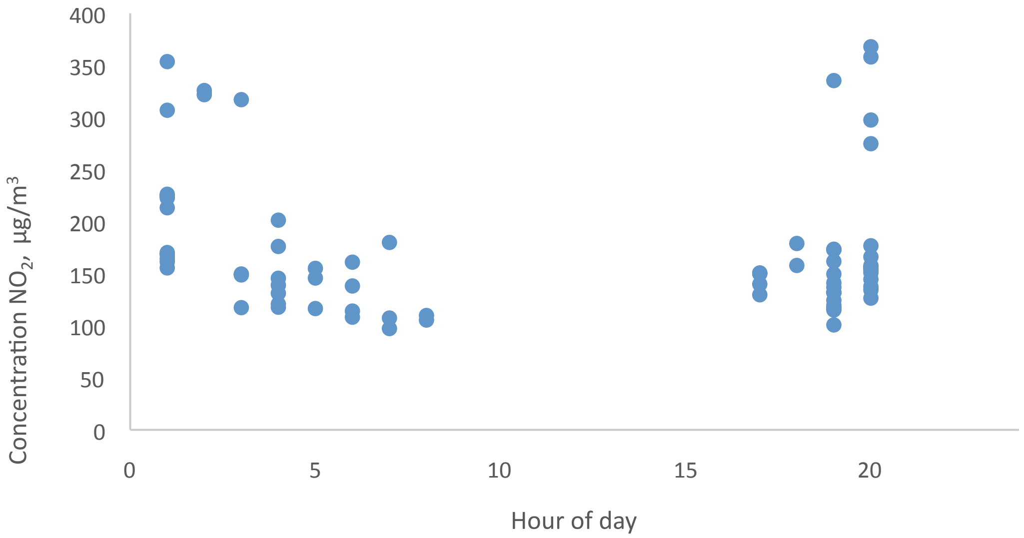

Figure 14: Hour of day for 8 highest 1-hr NO_2 concentrations at discrete receptors, outage scenario.

Although these scenarios may not represent actual emissions presently, for both Facebook and Apple they are possible within the limitations set in their Air Contaminant Discharge Permits. Air quality issues can be of concern even when emissions are within permit limitations. Given the results of these simulations, the next steps forward for regulators could include: further modeling, limitations on testing (such as during inversions, hours of the day, or how many generators can operate concurrently), updated regulations, and monitoring (especially to get accurate NO_2 concentrations). Cloud based storage, and thus data centers, is an expanding industry. The energy consumption of such data centers all over the world is expected to double every five years, at a huge cost to both business and the environment (Shen, 2014). This growth in the size and number of data centers will come with increased power consumption. This additional power will require appropriate backup, and thus the potential for significantly increased emissions.

6.0 FUTURE WORK

The continued work on this study involves further analysis of 1st highest concentrations and analysis of monthly scenarios. To address the possible source of error in the exclusion of BPIP, all simulations will be run again using BPIP. Monthly scenarios will also be re-run as a potential to emit (PTE) simulation. For the PTE cases, emission factors will be calculated from PSEL (tons/year of $PM_{2.5}$ and NO_2). EPA's Environmental Benefits Mapping and Analysis Program – Community Edition (BenMAP-CE) will be used to estimate the health impacts and economic values associated with changes in ambient air pollution, such as the differential concentrations of NO_2 and $PM_{2.5}$ calculated with AERMOD (http://www2.epa.gov/benmap). The PTE scenario and the incorporation of BenMAP-CE will allow consideration of the possible health risks and costs if the facilities operate to the extent their permits allow.

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