# Comparison of Near-field CFD and CALPUFF Modelling Results around a Backup Diesel Generating Station

**Control #17**

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## ABSTRACT
An air quality assessment was completed in support of a permit renewal application for a backup diesel generating station in Dawson City, Yukon. Due to the fact that the plant is situated in a valley and experiences stagnant conditions each year that can inhibit the movement of air, the CALPUFF model was considered appropriate to determine the effect of plant emissions on community air quality. However, because it was also anticipated that building downwash would be a primary factor in determining maximum predicted contaminant concentrations in close proximity to the powerhouse, a computational fluid dynamics (CFD) modelling analysis was also undertaken to verify the accuracy of near-field CALPUFF modelling results.

The diesel engines at the station are housed in a low building (<5 m), vented through short, curved exhaust stacks such that the exhaust gas is released horizontally rather than vertically. Emissions from four diesel engines, ranging in size from 800 to 1500 kW, were modelled in CALPUFF as individual point sources for both actual operations in 2010 and 2011, as well as for a hypothetical scenario of maximum sustained operation at 100% capacity factor. Based on the highest predicted concentrations from CALPUFF modelling, meteorological conditions conducive to building downwash were identified and selected for CFD modelling.

The CFD modelling results indicated that the predicted concentrations due to building downwash were closely correlated with wind speed, with the highest concentrations occurring with the highest wind speeds. The CFD modelling results were consistent with those derived from the CALPUFF model, with CFD maximum predicted concentrations being less than 10% higher than those estimated using the CALPUFF model. However, whereas the CALPUFF model predicted the maximum point of impingement to occur at the facility property line beside the powerhouse, the CFD model predicted the maximum concentrations to occur 10-20 metres from the property line.

The comparison of modelling results showed that the differences between the maximum predicted contaminant concentrations in close proximity to the source for building downwash

effects derived using the CALPUFF model were not very different from those that would be derived from a more complex simulation of wind flow around a small building using CFD modelling techniques. The analysis provides justification for using the CALPUFF model to represent near-field contaminant concentrations in similar regulatory applications. In addition, the CFD and the CALPUFF analyses were performed for higher building heights or higher stacks. Additional analysis would be required to verify whether the two models would continue to provide similar results for more complex building configuration stacks.

## INTRODUCTION

The Yukon Energy Corporation (YEC) operates a diesel power plant in Dawson City, Yukon. The primary purpose of the power plant is to provide backup power generation in support of hydroelectric power generation. In 2010 and 2011, the plant produced a total of 2933 MWh and 2398 MWh, respectively from four units. The plant is located on the southwestern edge of the city, with no buffer zone between the powerhouse and the facility property line as indicated in Figure 1. As part of the plant's application for licence renewal, a dispersion modelling analysis using the CALPUFF model was completed to determine the maximum predicted air contaminant concentrations for the criteria air pollutants CO, $NO_x$, $SO_2$ and $PM_{2.5}$.

Figure 1: YEC Power Plant in Dawson City

Since it was also anticipated that building downwash would be a primary factor in determining maximum predicted contaminant concentrations in close proximity to the powerhouse, a Computational Fluid Dynamics (CFD) modelling analysis was also undertaken to verify the accuracy of near-field CALPUFF modelling results.

## EMISSIONS

The diesel engine characteristics for the four stationary engines (DD1-DD5) and one mobile engine (YM1) at the Dawson City diesel generating plant are listed in Table 1. The mobile unit (YM1) is seldom used and was operated for only a few hours in 2011. The engines listed in Table 1 are 'uncontrolled', meaning that there are no devices that treat the exhaust before it is vented to the atmosphere. In terms of emission standards established by the U.S. Environmental Protection Agency (USEPA) (and which are commonly referenced in Canada), the engines can be further classified as 'pre-Tier'. Pre-Tier engines were not subject to the USEPA emissions standards since such standards were not developed prior to 2000.

**Table 1.** YEC Diesel Engine Characteristics.

| Unit No. | Prime Mover Manufacturer | Model | MCR Rating (kW) | Sustained Generation (kW) | In-service Date |
|---|---|---|---|---|---|
| **DD1** | Caterpillar | 3512 | 800 | 720 | 1988 |
| **DD2** | Caterpillar | 3516 | 1000 | 920 | 1987 |
| **DD3** | Caterpillar | 3516 | 1000 | 920 | 1990 |
| **DD5** | Caterpillar | 3606 | 1500 | 1400 | 1996 |
| **YM1** | Caterpillar | 3516 | 1000 | 920 | 1990 |

Actual measured emission rates for the Dawson City engines were not available. Instead, emissions were based on stack sampling results obtained for seven similar units at the YEC Whitehorse plant. Table 2 lists the average of the measured emission rates for the seven diesel generator units in Whitehorse.

**Table 2**. Average Measured Emission Factors for YEC Diesel Engines in Whitehorse.

| YEC Unit | Average Emissions (g/kWh) | | | | |
|---|---|---|---|---|---|
| | **CO** | **$NO_x$** | **$SO_2$** | **$PM_{10}$** | **$PM_{2.5}$** |
| Mean of Seven Units | 0.516 | 8.82 | 0.0141 | 0.183 | 0.134 |

The measured $PM_{10}$ emission factors include both the filterable and condensable portions of particulate matter (PM) emission rates. The measured $PM_{2.5}$ emission factors include the filterable $PM_{2.5}$ plus the condensable portion of PM emissions. Only the $PM_{2.5}$ emissions were evaluated for this study since there are no ambient air quality standards for $PM_{10}$ in the Yukon.

### Worst Case Emission Scenario

A hypothetical, worst-case power generation scenario was used which assumes that the plant could operate with four stationary units (DD1, DD2, DD3 and DD5) running at their maximum sustained generation rate continuously for an entire year (i.e., 100% capacity factor), generating a maximum of 95.0 MWh per day and 34,689.6 MWh per year. The diesel generator emissions for this scenario were modelled using 2010 meteorology. Since no meteorological observation data were available for the site, meteorological data were extracted from a prognostic model for 2010.

## MODELLING APPROACH

Emissions from the YEC diesel generators at Dawson were modelled using a refined dispersion model called the California Puff Model (CALPUFF)[1]. CALPUFF is a recommended model in the British Columbia Dispersion Modelling Guidelines[2] and the modelling guidelines for other Canadian provinces for situations involving complex circulation patterns that can influence the advection and dispersion of air pollutants. Due to the fact that Dawson is situated in a valley and experiences stagnant conditions each year that can inhibit the movement of air, the CALPUFF model was considered appropriate to investigate the effect of YEC emissions on community air quality.

SENES derived meteorological data sets for Dawson from a prognostic meteorological model to use as input to the CALMET/CALPUFF modelling system. This approach had previously been applied to diesel generator plants in Watson Lake and Old Crow, Yukon in 2009, as well as for solid waste incineration operations in six small communities in the Yukon in 2009, and has been accepted by the Yukon Government.

The powerhouse at the YEC Dawson plant is situated right on the property line, with a public road (i.e., Fifth Avenue) beside it, and the exhaust stacks on the stationary diesel units are curved such that the exhaust is released horizontally rather than vertically (in the modelling release is taken as vertical, because of high exit temperatures, velocities and some of the stacks are under $45^0$ angle). The powerhouse is 4.86 m high, 25 m long and 12.6 m wide, and the short exhaust stacks lie well within the building wake effects zone. For these reasons, building downwash effects on the exhaust plumes can potentially result in higher ground-level concentrations.

Although the CALPUFF model does have the ability to simulate building downwash effects, there was some uncertainty about the accuracy with which the CALPUFF model can do so in such close proximity to the powerhouse building. Consequently, model output from the CALPUFF modelling analysis was used to identify those specific meteorological conditions which lead to maximum predicted concentrations near the YEC plant due to building downwash effects. These meteorological conditions were then used to estimate maximum predicted concentrations close to the powerhouse using CFD modelling methods.

The CFD modelling approach is based on the solution of single-phase, steady-state, 3-D conservation equations[4,5] for mass, momentum and energy of air-pollutant mixture under proper boundary conditions accounting for the meteorological conditions, the building structures and the pollutant release characteristics. The commercial, general-purpose CFD software, PHOENICS[5], is used as a framework and a solver. It has been extensively used and validated for gas dispersion modelling in [6,7,8] and other papers.

CFD modelling is used to provide quantitative estimates of near-field dispersion of pollutants in complex flow situations. These estimates are based on the analyses of 3-D distributions of mass concentration of pollutants in the domain of interest under various meteorological conditions and contaminant release conditions.

## Meteorology

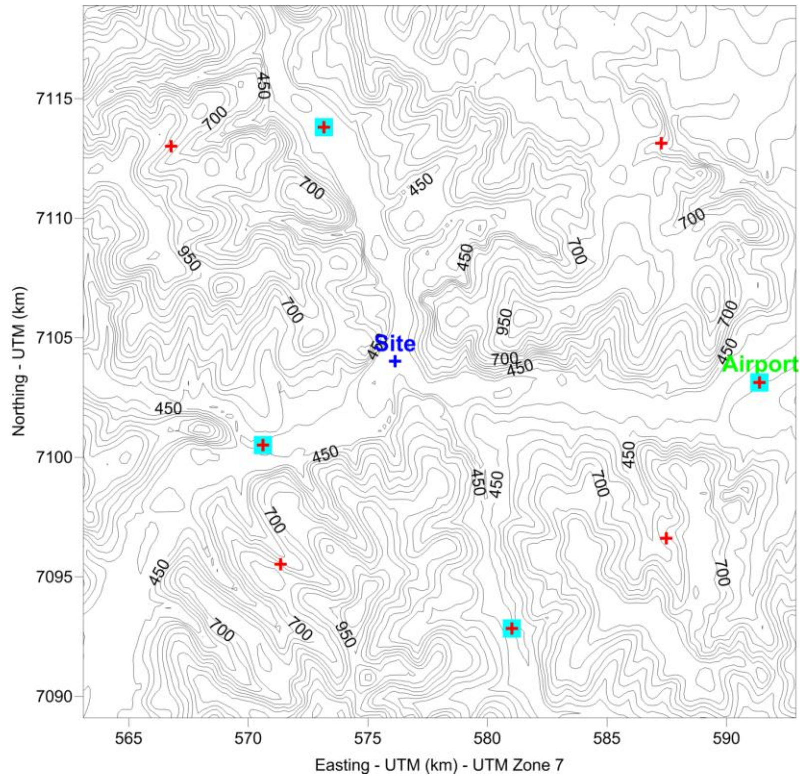
The CALPUFF modelling system includes a meteorological processor called CALMET. CALMET is used to produce a three-dimensional simulation of the atmosphere, based on the output from a larger scale weather model. The resultant CALMET fields govern the advection and dispersion of emissions in the CALPUFF dispersion model itself.

The prognostic weather model used was the Non-hydrostatic Mesoscale Model (NMM)[9,10,11] core of the Weather Research and Forecasting (WRF) system developed by the National Oceanic and Atmospheric Administration (NOAA), National Centers for Environmental Prediction (NCEP). The approach used to develop meteorological data for Dawson City was to use the WRF-NMM model in the hindcasting mode.

Hindcasting uses large-scale analysis fields for the world that are generated by Numerical Weather Prediction (NWP) centers in the US. The analysis fields are the real observed data, pre-processed to balance all physical forces into three-dimensional meteorological fields that can be used for boundary conditions in high resolution simulations. In hindcasting mode, the analysis fields from NCEP provided every 6 hours are used for boundary conditions and a higher resolution ‘forecast’ is made using a full weather model (WRF-NMM) for a 24-hour period each day. The analysis field boundary conditions nudge the forecast in the direction of the observations. Such nudging occurs at the domain boundaries, so that the model physics can generate the finer scale circulations within the area of interest. The results of the model are reformatted into pseudo-surface and upper air observations and used as the inputs into CALMET.

The weather model analysis was performed based on the Global Analyses Data for 2010 and run in nested mode. The resolution of the smaller modelling domain was approximately 1 km. The CALMET model was run based on the inputs from the meso-scale weather model. Figure 2 presents the locations in the modelling domain where the pseudo-surface (at the YEC plant location and at the locations with red crosses with blue shading) and pseudo-upper air data (red crosses) were generated for the CALMET model inputs.

Figure 2: Pseudo Surface and Upper Air Stations Used as Input for CALMET




Observation data were available at the Dawson airport only for the daytime hours. Because of this data limitation, the airport station data was not used as input for the CALMET modelling, but was used as a check for the meteorological modelling results.

In addition to meteorological data, CALMET requires a number of settings and additional datasets to configure the modelling domain (listed in Table 3).

**Table 3.** CALMET Configuration.

| Parameter | CALMET Configuration |
|---|---|
| Size of Modelling Domain | 30 km by 30 km, centered on YEC diesel plant |
| Grid Horizontal Resolution | 200 m by 200 m |
| Grid Vertical Resolution | 9 levels (0 to 3300 m) |
| Input Terrain (elevation) | 30 m DEM from Geomatics Canada |
| Input Vegetation (land use) | Global Land Use ~ 300m resolution |
| Wind Field Model | On, with model defaults |
| Wind Interpolation | RMAX1,2 = 30,30km |
| Terrain Influence on winds | TERRAD = 2 km |

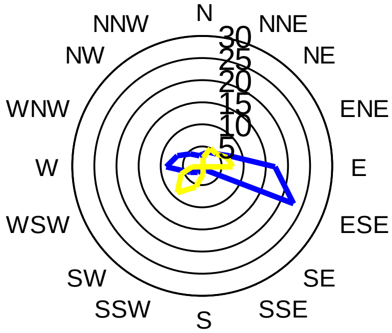
Surface energy fluxes and wind flow are influenced by local terrain and vegetation. The terrain was categorized by 30 m digital elevation model (DEM) files from Geomatics Canada. Land use category was configured by extracting information from the GLOBCOVER Land Cover product v2.1 released to the public in late September 2008 which is the highest resolution (300 m) Global

Land Cover product ever produced and is based on data collected at full resolution from January 2005 to June 2006.

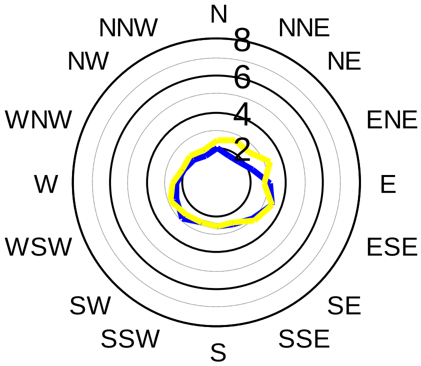
Figure 3 provides the wind rose comparison between observations of wind flow and the results of wind flow simulations using CALMET at the location of the meteorological station (i.e., Dawson airport) for day-time hours only. As indicated in Figure 3, the observation data show 46.6% of calms, compared with only 6.78% of calms in the CALMET data. CALMET assigns a wind direction for those hours in which the airport data for calms would assign no wind direction. This is considered to be the primary reason for the differences in observed and CALMET predicted wind direction in Figure 3. The CALMET wind rose is in the alignment with the valley orientation.

Figure 3: Windrose Diagram, EC Dawson Surface Station – 2010 vs. CALMET Grid Point (142,71)

**Wind Direction Frequency (%)**




**Average Wind Speed (m/s)**




Note: This is direction wind blows **from**

Percentage Calms = 6.78% - CALMET, Observation 46.6 %.

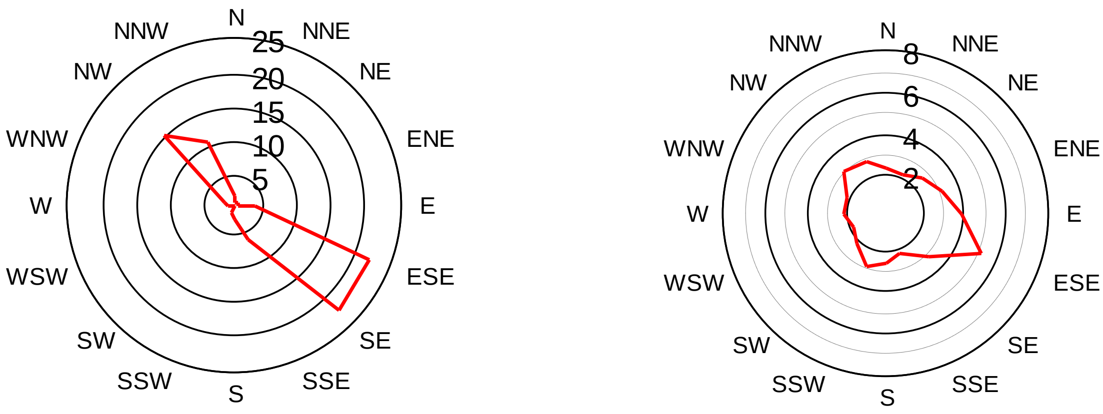
— Dawson Meteorological Station - day-time hours

— CALMET Extracted Data at Grid close to the Meteorological Station

Figure 4 presents the wind rose diagram for the location of the YEC plant site, as generated using the CALMET model. The data indicate that wind direction at the plant site is strongly influenced by the orientation of the two valleys to the east and northwest of the plant. While the predominant wind direction is from the southeast (SE) through east-southeast (ESE), winds from the northwest (NW) and north-northwest (NNW) together account for about 25% of the total hours in the year. Note also that the strongest winds are from the ESE, and that average annual wind speeds greater than 3 m/s are typically related to winds from the ENE through to the SE.

**Figure 4: CALMET Generated Wind Rose Diagram, YEC Dawson Plant Site - 2010**

**Wind Direction Frequency (%)** **Average Wind Speed (m/s)**




Note: This is direction wind blows **from** Percentage Calms = 6.13%

## Source Characteristics

Emissions from the YEC engines were modelled as individual point sources with the characteristics defined in Table 4. In the absence of measured exhaust gas temperature and flow rate data for the YEC units, exhaust temperature was based on performance data for a 900 kW Caterpillar Model 3512. The exhaust gas flow rates were interpolated from performance data as a function of power output (between 545 kW and 2000 kW) for the Caterpillar engine models 3512, 3516 and 3412C.[12] All four stationary units (DD1-DD3 and DD5) were used in the worst-case emission modelling scenario.

**Table 4.** Dawson Emission Configuration for CALPUFF.

| Dawson Unit | UTM Northing (km) | UTM Easting (km) | Stack Height (m) | Stack Diameter (m) | Exhaust Exit Velocity (m/s) | Exhaust Temperature ($^oC$) |
|---|---|---|---|---|---|---|
| **DD1** | 576.141 | 7104.028 | 6.4 | 0.305 | 34.2 | 450.0 |
| **DD2** | 576.140 | 7104.025 | 7.6 | 0.305 | 42.4 | 450.0 |
| **DD3** | 576.139 | 7104.024 | 6.7 | 0.305 | 42.4 | 450.0 |
| **DD5** | 576.134 | 7104.015 | 7.6 | 0.508 | 23.7 | 450.0 |
| **YM1** | 576.135 | 7104.016 | 5.6 | 0.305 | 42.4 | 450.0 |

Note: Building height was 4.86 m.

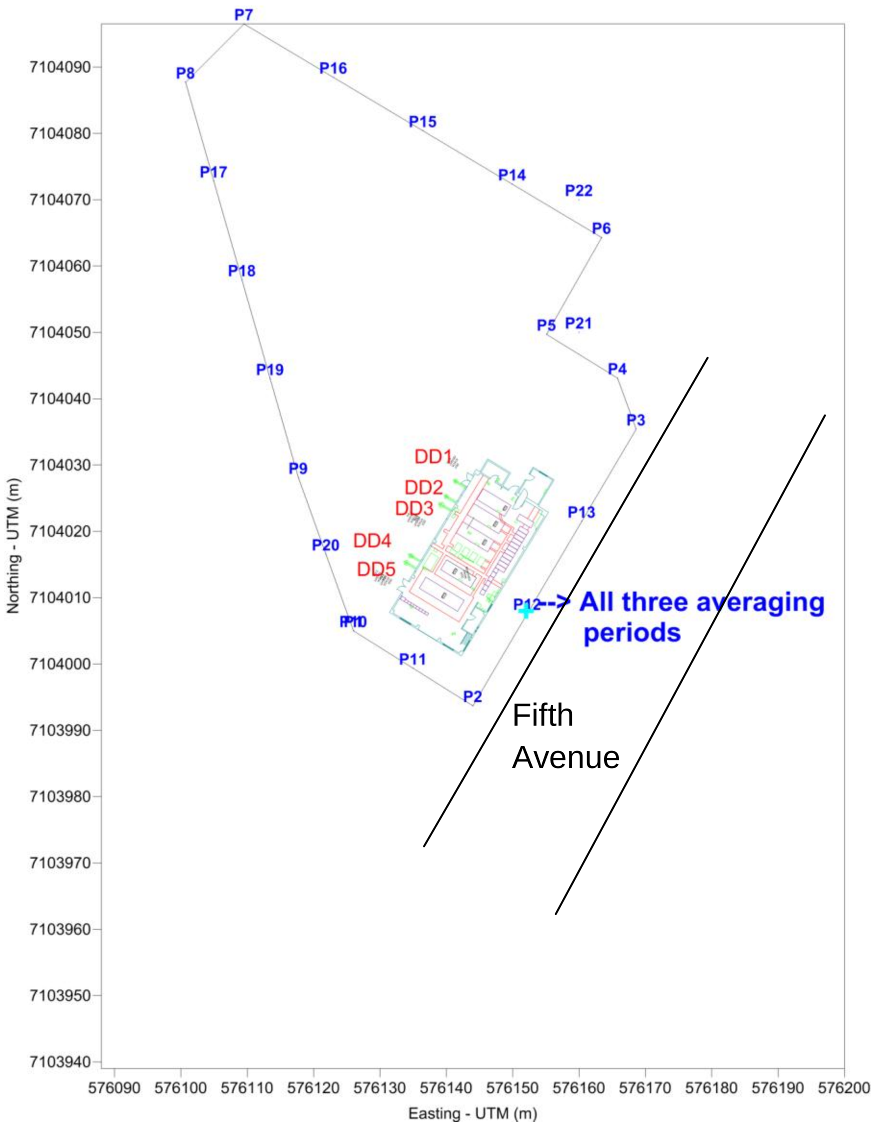
CALPUFF was additionally configured to represent wet removal of pollutants due to precipitation and building downwash. The latter mechanism is particularly important since the engine stacks at the YEC diesel plant are not high enough to escape building wake effects in the wind flow. The physical dimensions of the stacks and the building were used to determine downwash parameters for the model[15], which are internally accessed depending on the characteristics of the wind flow on any particular hour. A more refined assessment of the effect of building wake on plume dispersion was evaluated using CFD modelling.

## Receptor Grid

Receptor spacing denotes the specific spacing at which the model is set to estimate ground level concentrations. Estimates of ambient air quality concentrations were produced on a regular grid every 20 m within 200 m of the Dawson diesel plant, every 50 m between 200 and 500 m from the plant and then every 200 m for the remainder of the domain.

Figures 5 shows the discrete receptor points along the YEC property line used to identify the Maximum Point of Impingement (Max POI) for the highest $NO_x$ and $PM_{2.5}$ concentrations for the worst-case modelling scenario in the analysis. For this scenario, the Max POI for 1-hour and 24-hour average NOx and 24-hour average $PM_{2.5}$ all occur at the same location (P12) on the property line. For the worst-case modelling scenario, the Max POI occurs along the southern end of the property line along Fifth Avenue and corresponds to winds from the north and north-northwest.

Figure 5: Location of Max POI for $NO_x$ and $PM_{2.5}$ –All Three Averaging Periods – Worst Case Emissions Scenario



## DISCUSSION OF CALPUFF MODELLING RESULTS

The maximum concentrations are those predicted by the model over the year and each concentration value could occur in any given hour.

Table 5 lists the maximum predicted concentrations for all four contaminants at the Maximum Point of Impingement (Max POI) location for the worst-case power generation scenario. This scenario represents a hypothetical scenario of operations, assuming the four stationary diesel generators running 100% of the time all year. In reality, it would be physically impossible for YEC to achieve this level of power generation.

**Table 5.** CALPUFF Maximum Predicted Incremental Concentrations for Worst-Case Power Generation Scenario (excluding background air quality).

| Receptor Location | Maximum Concentrations (µg/m$^3$) | | | | | | |
|---|---|---|---|---|---|---|---|
| | CO | | $NO_x$ | | $SO_2$ | | $PM_{2.5}$ |
| | 1-hour | 8-hour | 1-hour | 24-hour | 1-hour | 24-hour | 24-hour |
| Max POI | 351.0 | 338.0 | 5999.9 | 5197.1 | 9.5 | 8.3 | 78.9 |

## $NO_x$ Concentrations

The highest predicted 1-hour average $NO_x$ concentration occurs very close to the plant at the Max POI at 5999.9 µg/m$^3$. However, maximum predicted concentrations fall rapidly with distance from the plant.

The highest 24-hour average $NO_x$ concentration at the Max POI is 5197.1 µg/m$^3$. The second highest predicted concentration at the Max POI was 4426.0 µg/m$^3$. Both the highest and second highest 24-hour average $NO_x$ concentrations were predicted to occur on consecutive days (August 18$^{th}$ and 19$^{th}$), coinciding with the highest and second highest predicted 24-hour average $PM_{2.5}$ concentrations (see Table 6). The highest $NO_x$ and $PM_{2.5}$ concentrations were all predicted to occur on days in which building downwash effects were the dominant factors affecting emissions from the power plant. Beyond the immediate vicinity of the plant, the highest 24-hour average $NO_x$ concentrations are predicted to occur on the hillside across the river WNW and SSE of the plant at about 100-200 µg/m$^3$.

## $PM_{2.5}$ Concentrations

The highest $PM_{2.5}$ concentration was predicted to occur in the immediate vicinity of the plant at 78.9 µg/m$^3$. Concentrations greater than 5 µg/m$^3$ are also predicted to occur across the river WNW of the plant.

**Table 6.** Meteorological Conditions Conducive to Producing Highest Incremental $PM_{2.5}$ Concentrations (excluding background air quality)

| Date | Max. Daily $PM_{2.5}$ Concentration ($\mu g/m^3$) | Median Daily Wind Speed (m/s) | Median Daily Wind Direction (degrees) | Median Daily P-G Stability Class | Ave. Daily Mixing Height (m) |
|---|---|---|---|---|---|
| 18-Aug | 78.9 | 10.8 | 324.3 | 4 | 1130.2 |
| 19-Aug | 68.2 | 8.5 | 326.6 | 4 | 901.9 |
| 30-Jun | 59.8 | 7.7 | 328.6 | 4 | 1134.4 |
| 27-Sep | 55.9 | 6.8 | 325.8 | 4 | 522.0 |

Note: P-G = Pasquill-Gifford Atmospheric Stability Class category.

The same meteorological conditions which lead to the highest and second highest predicted 24-hour average $PM_{2.5}$ concentrations in Table 6 also produced the highest and second highest predicted 24-hour average $NO_x$ concentrations. Thus, northwest winds with median daily wind speeds greater than 8.5 m/s can result in high concentrations of both $NO_x$ and $PM_{2.5}$ when all four stationary diesel generators are operating at full capacity, simultaneously.

Therefore, the highest $PM_{2.5}$ concentration at the Max POI occurs at the YEC facility property line when median daily wind speeds exceed 8.5 m/s with winds from the NW-NNW, with neutral (P-G Stability Class 4) atmospheric conditions. The highest concentrations were predicted to occur with the highest wind speeds (>10 m/s) for NW winds (~325 degrees) and the highest mixing heights (>900 m).

## CFD DISPERSION MODELLING ANALYSIS

The CFD dispersion modelling analysis was completed by Dr. Vladimir Agrannat.[17]

### Meteorological Conditions Selected for CFD Analysis

Because of the computational demands for CFD modelling, such modelling is typically only conducted for a few selected meteorological conditions. The CALPUFF dispersion modelling analysis was used to identify a number of meteorological conditions that led to elevated concentrations of $NO_x$ and/or $PM_{2.5}$ either at the property line or at locations close to the property line. Four cases were chosen from this analysis:

*Case 1* - NW winds at 320˚ and 11 m/s, corresponding to Julian Day 230 (hour 20) during which the highest predicted hourly averaged $NO_x$ and $PM_{2.5}$ concentrations and the day on which the 24-hour averaged $NO_x$ concentration was predicted to reach 5197.1 $\mu g/m^3$ at receptor P12 and the $PM_{2.5}$ concentration was predicted to reach 78.9 $\mu g/m^3$ at receptor P12;

*Case 2* - W winds at 260.7˚ and 4.2 m/s, corresponding to a day during which the hourly averaged $NO_x$ concentration was predicted to be 3636.1 $\mu g/m^3$ at receptor P3;

*Case 3* - NE winds at 31.6˚ and 5.6 m/s, corresponding to a day during which the hourly averaged $NO_x$ concentration was predicted to be 4213.2 $\mu g/m^3$ at receptor P11; and

*Case 4* - NW winds at 320˚ and 2 m/s.

Case 4 was completed for NW winds at 320˚ and 2 m/s winds which would test the effect of lower wind speed for both $NO_x$ and $PM_{2.5}$ for NW winds. In addition, a hypothetical test case (Case 1a) was run with the same wind direction and wind speed as Case 1 (i.e., NW winds at 320˚ and 11 m/s), but with building and stack heights increased by a factor of 2.5 times those used in Case 1 only in order to determine the effect of these changes on differences in predicted concentrations using the CFD and CALPUFF models.

## Discussion of CFD Modelling Results

Table 7 provides a summary of the maximum predicted 1-hour average contaminant concentrations at the key receptor points along the property line (P1 to P9) downwind of the emission stacks and at the nearest residential receptor locations (R2 and R3) in the vicinity of the power plant, for each of the four CFD case runs. The locations of receptors P1-P22 are indicated in Figure 5. Also listed in Table 7 are the maximum predicted concentrations anywhere in the CFD modelling domain (equivalent to the concept of Max POI for CALPUFF modelling, though not occurring in the same location as the CALPUFF Max POI).

**Table 7.** Maximum Predicted 1-hour Average Incremental Contaminant Concentrations from CFD Modelling (excluding background air quality).

| **Case/Receptor ID** | | **Maximum 1-hour Concentrations (μg/m$^3$)** | | | |
|---|---|---|---|---|---|
| | | **CO** | **$NO_x$** | **$SO_2$** | **$PM_{2.5}$** |
| Case 1 | R2 | 39.1 | 668 | 1.1 | 10.1 |
| | P2 | 12.8 | 219 | 0.4 | 3.3 |
| | Max. Concentration | 375.0 | 6400 | 10.3 | 97.0 |
| Case 2 | R3 | 4.8 | 81.2 | 0.1 | 1.2 |
| | P3 | 33.2 | 567 | 0.9 | 8.6 |
| | Max. Concentration | 159.0 | 2725 | 4.4 | 41.3 |
| Case 3 | P1 | 22.8 | 389 | 0.6 | 5.9 |
| | Max. Concentration | 88.3 | 1515 | 2.4 | 23.0 |
| Case 4 | R2 | 1.6 | 27 | 0.04 | 0.4 |
| | P2 | 0.06 | 0.9 | <0.002 | 0.01 |
| | Max. Concentration | 23.3 | 399 | 0.6 | 6.1 |

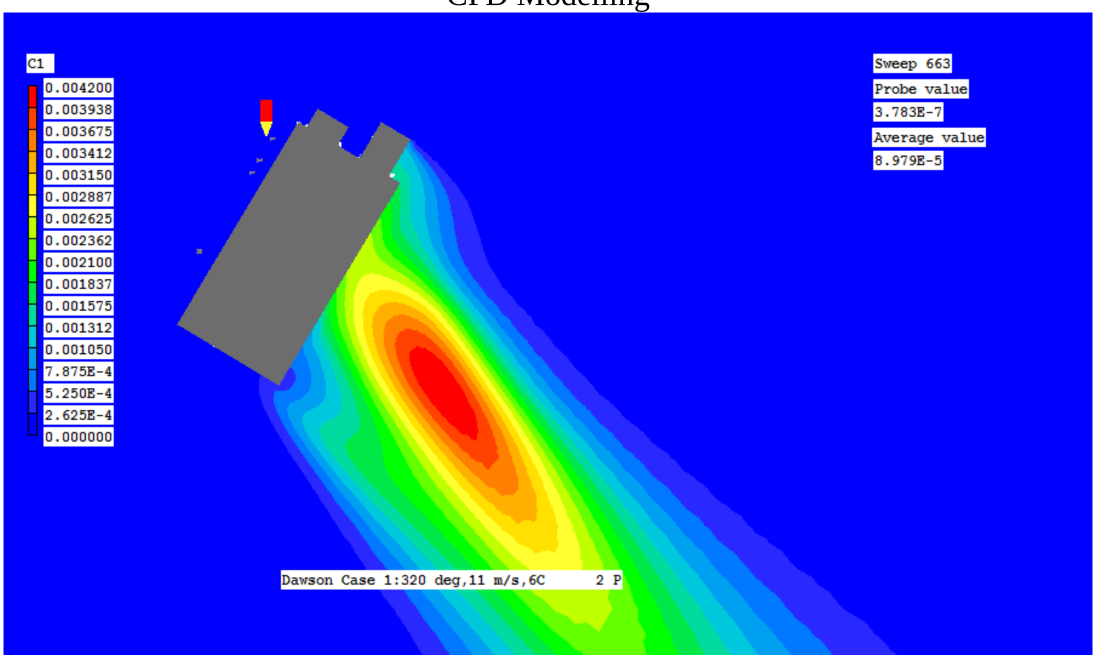
Table 8 indicates that the Case 1 CFD modelling results for maximum predicted concentrations are consistent with the Max POI concentrations derived from CALPUFF. For each of the four contaminants, the CFD results are only 6-8% higher than the CALPUFF estimates. Thus, the CFD modelling results serve to confirm the overall reliability of the CALPUFF modelling analysis.

**Table 8.** Comparison of Maximum Predicted Contaminant Concentrations for CFD and CALPUFF Modelling – Case 1.

| Contaminant | Maximum Predicted 1-hour Average Concentrations (µg/m$^3$) | |
|---|---|---|
| | CFD | CALPUFF |
| **CO** | 375 | 351 |
| **$NO_x$** | 6400 | 5999.9 |
| **$SO_2$** | 10.3 | 9.5 |
| **$PM_{2.5}$** | 97.0 | 91.1 |

The primary difference between the CALPUFF and CFD results is in the location of the maximum predicted concentrations. Whereas the CALPUFF model predicted the Max POI to occur at the facility property line (location P12 on Figure 5), the CFD model predicts the maximum concentrations to occur 10-20 m from the property line. As indicated in Figure 6, the location of the maximum 1-hour average concentration predicted using the CFD model is on the eastern side of Fifth Avenue, east of the YEC powerhouse. Therefore, from the perspective of the highest 24-hour average $NO_x$ and $PM_{2.5}$ concentrations in Table 8 predicted using the CALPUFF model, the CFD modelling analysis confirms that these elevated concentrations would occur in close proximity to the YEC plant.

Figure 6: Location of Maximum Predicted Contaminant Concentrations in Case 1 CFD Modelling



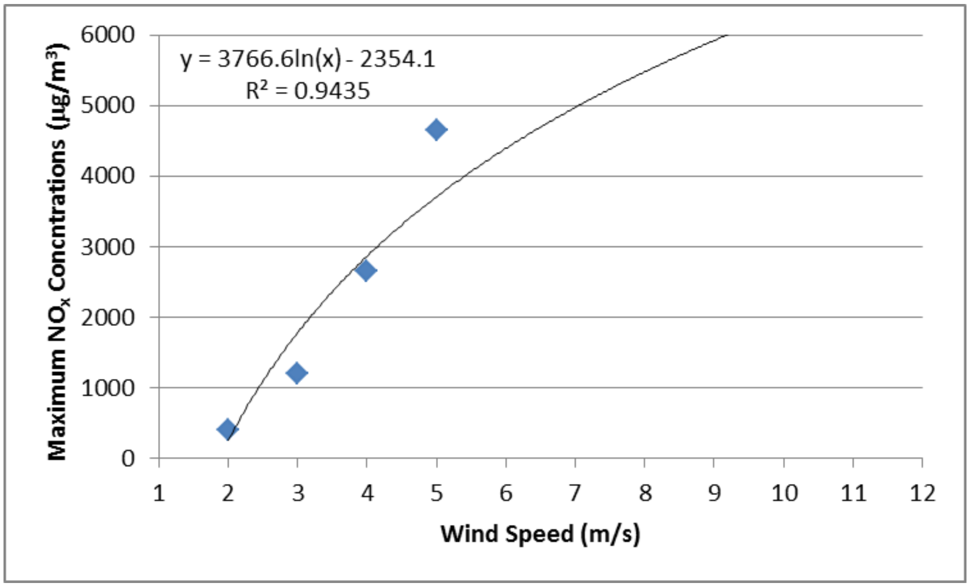

In order to verify the effect of lower wind speeds on maximum predicted $NO_x$ concentrations when four of the YEC engines are operating simultaneously, Case 1 was re-run three more times using the CFD model at varying wind speeds in order to determine the effect of wind speed on the maximum predicted $NO_x$ concentrations. These results are summarized in Table 9.

**Table 9.** Effect of Wind Speed on CFD Predicted Incremental $NO_x$ and $NO_2$ Concentrations Case 1 - NW Winds (excluding background air quality).

| Location | Contaminant | Wind Speed (m/s) | | | | |
|---|---|---|---|---|---|---|
| | | 2 | 3 | 4 | 5 | 11 |
| | | Concentration (μg/m$^3$) | | | | |
| R2 | $NO_x$ | 27 | 191 | 390 | 587 | 668 |
| Max. Concentration | $NO_x$ | 399 | 1195 | 2650 | 4650 | 6400 |

The data in Table 9 indicate that the 1-hour average $NO_x$ concentrations are closely correlated with wind speed, with the highest $NO_x$ concentration occurring with the highest wind speed. Figure 7 provides a plot of the correlation between wind speed and CFD maximum predicted $NO_x$ concentrations.

Figure 7: Correlation between Wind Speed and Maximum Predicted Incremental $NO_x$ Concentration (excluding background air quality)




## CALPUFF VS CFD FOR THE CASE OF HIGHER STACKS AND BUILDING

The CFD Case 1 (NW wind direction and wind speed of 11 m/s) was re-run as Case 1a with the CFD and CALPUFF models, but with the stack and building heights increased for 2.5 times from the original values. This analysis was completed as a hypothetical test case to evaluate the effects of changing the building height and the stack height on CALPUFF and CFD predicted contaminant concentrations. The results of comparison between those two runs are presented in Table 10.

**Table 10.** Maximum Predicted 1-hour Average Incremental Contaminant Concentrations from CFD Modelling (excluding background air quality).

| **Case/Receptor ID** | | **Concentration (μg/m$^3$)** | | | |
|---|---|---|---|---|---|
| | | **CO** | **$NO_x$** | **$SO_2$** | **$PM_{2.5}$** |
| Case 1 | R2 | 39.1 | 668 | 1.1 | 10.1 |
| | P2 | 12.8 | 219 | 0.4 | 3.3 |
| | Max. Concentration | 375.0 | 6400 | 10.3 | 97.0 |
| Case 1a-Stack and Buildings Higher | R2 | 9.5 | 162.5 | 0.26 | 2.5 |
| | P3 | 19.1 | 326.4 | 0.52 | 4.9 |
| | Max. Concentration | 88.4 | 1509.9 | 2.4 | 22.8 |

Notes: $NO_2$ concentrations estimated as 5% of $NO_x$ concentrations
n/a - not applicable

Table 11 provides a direct comparison of CFD and CALPUFF estimates of predicted contaminant concentrations for the same releases and common meteorology in Case 1a. The agreement between the two very different models is within 10-11% and suggests that the CALPUFF model is capable of providing reasonably reliable estimates of near-field predicted contaminant concentrations in which building wake effects are a dominant factor in contaminant dispersion.

**Table 11.** Comparison of Maximum Predicted Contaminant Concentrations for CFD and CALPUFF Modelling – Case 1a.

| **Contaminant** | **Maximum Predicted 1-hour Average Concentrations (μg/m$^3$)** | |
|---|---|---|
| | **CFD** | **CALPUFF** |
| **CO** | 88.4 | 78.8 |
| **$NO_x$** | 1509.9 | 1346.5 |
| **$SO_2$** | 2.4 | 2.2 |
| **$PM_{2.5}$** | 22.8 | 20.4 |

It is also worth considering the CFD predicted air flow around the powerhouse for the two cases of different building heights as indicated Figure 8. Figure 9 provides a comparison of the CFD predicted hourly $PM_{2.5}$ concentrations for Cases 1 and 1a.

Figure 8: CFD Predicted Air Flow Comparison

a) Building Height 4.86m b) Building Height 12.15 m

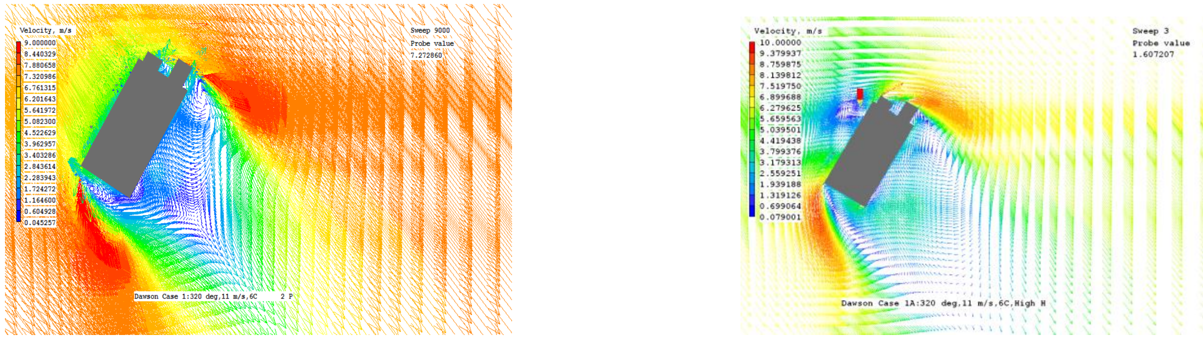
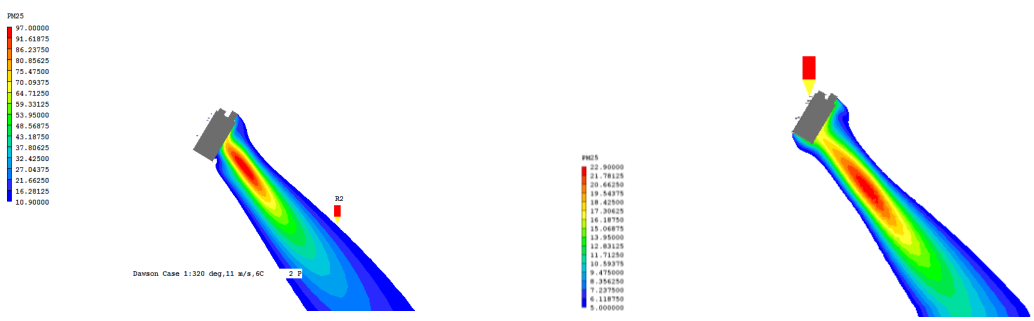


Figure 9: CFD Predicted $PM_{2.5}$ Concentrations for Different Building Heights

b) Building Height 4.86m b) Building Height 12.15 m



These results indicate that the increase in stack building heights decreased the maximum predicted concentrations of contaminants by about a factor of 4.2 based on the CFD model and a factor of 4.4 based on the CALPUFF model. Therefore, the effect of increasing stack and building heights on maximum predicted concentrations was similar for the two models.

## SUMMARY

The emissions from a small diesel-powered generating station were evaluated using two different modelling methods to verify the effects of building downwash on predicted near-field contaminant concentrations. The CFD modelling results are consistent with those derived from the CALPUFF model, with CFD results being only 6-8% higher than those estimated using the CALPUFF model when using the original stacks and building heights. For the test runs using hypothetically higher stack and building height, the results derived from the CFD model were about 10-11% higher than those derived from the CALPUFF model. Therefore, while the CFD model consistently provided higher maximum predicted concentrations than the CALPUFF model, the analysis does indicate that the CALPUFF model can provide reasonably reliable estimates of near-field (i.e., less than 50 m) contaminant concentrations in situations dominated by building downwash effects for relatively small sources.

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**KEY WORDS**

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