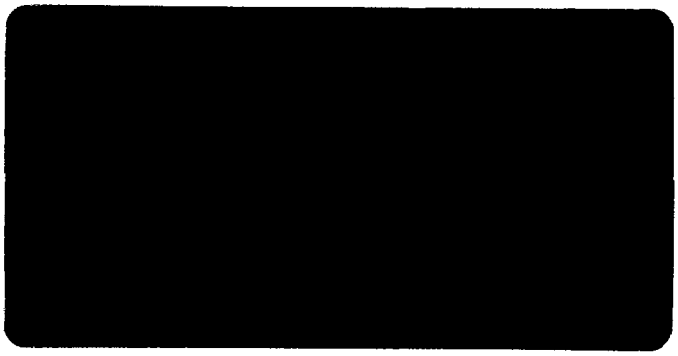

DILLON

AIR DISPERSION MODELLING OF ROASTER STACK EMISSIONS ROYAL OAK GIANT YELLOWKNIFE MINE YELLOWKNIFE, NORTHWEST TERRITORIES

M. M. DILLON LIMITED
Consulting Engineers,
Planners and
Environmental Scientists

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

Ore mined at the Giant Yellowknife Mine contains several gold carrier minerals, such as arsenopyrite, pyrite, and other metallic sulfides. These minerals are crushed and ground to produce a bulk gold sulfide concentrate that is passed through a two stage fluosolids roaster. In addition to the main discharge, this roasting process produces off gas rich in sulfur dioxide and arsenic trioxide which is passed through cyclones, Cottrell precipitators, and a baghouse prior to discharge to the atmosphere via the roaster stack.

The air dispersion modelling of sulfur dioxide and arsenic emissions from the Giant Yellowknife Mine roaster stack is outlined in this report. It is submitted in execution of the project initiated by request for proposals, dated August 23, 1994, jointly by the Northwest Territories Department of Renewable Resources and Royal Oak Mines, Inc. Project objectives are to both model the atmospheric dispersion of sulfur dioxide and arsenic emitted from the gold roaster stack using an appropriate USEPA dispersion model and to assess the effectiveness of emission control options in reducing ambient concentrations of emitted pollutants.

Background information about the site, the emission source, and local meteorology is summarized in Section 2. Model selection, the configuration of selected model runs, and baseline modelling results are described in Section 3. Modelling results are evaluated by comparison with ambient monitoring results in Section 4. Section 5 contains a sensitivity analysis where the individual and combined effects of stack discharge parameters and mass emission rates are evaluated. Conclusions and recommendations are provided in Section 6.

2.0 BACKGROUND INFORMATION REVIEW

2.1 Site Data

Information regarding roaster stack emissions, site building and stack geometry, ground level and upper air meteorological data, and local topography were gathered to develop proper input files for execution of the desired modelling runs. Information on the gold roasting process, inplace emission control technologies, stack testing results, site building and stack dimensions, and ambient air monitoring results were provided by Royal Oak Mines Inc. and the GNWT Department of Renewable Resources. Surface and upper air meteorological data were purchased on disk from the Atmospheric Environment Service, Canadian Climate Centre in Downsview, Ontario.

2.2 Emission Source Data

Historical roaster stack test results have been reviewed and emission parameter values needed as model inputs have been calculated. Emission parameters, which include mass emission rates for both total arsenic and sulfur dioxide as well as mean exit gas velocity and temperature, have been calculated from stack test data provided and are summarized in Table 2-1.

While the mass emission rate for total arsenic was said to vary from 20 to 30 kg/day, measured values from sampling in 1991 and 1993, as shown in Table 2-1 were chosen for model runs. The mass emission rate for sulfur dioxide reportedly ranges in value from 30 to 65 x 10^3 kg/day. Mean values of exit gas velocity and temperature were determined as the arithmetic average of traverse point values measured during 1991 and 1993 stack sampling, as shown in Table 2-1.

2.3 Site Building and Stack Data

A detailed minesite layout showing building locations and dimensions was reviewed to determine if the roaster stack was located within the building wake area of influence of any nearby structures. While the stack was found to be within the influence areas of the two roaster buildings, the Cottrell precipitator and baghouse buildings, and the arsenic loadout building, none of the buildings were tall enough to produce a turbulent wake cavity high enough to intercept a portion of the roaster stack plume. It was

concluded that building wake effects did not exert an influence on the dispersion of roaster stack emissions.

Topographic maps of the minesite and surrounding area were reviewed to classify the terrain within the modelled area for use with either a simple or complex terrain dispersion model. Simple terrain models are meant to model dispersion over flat or rolling terrain where elevation differences within the model domain are less than or equal to one stack height (45.7 m.). It was concluded from this review that an area extending 7 km north of the stack, 7 km west of the stack, 7 km east of the stack, and 8 km south of the stack could be modelled with a simple terrain model.

Table 2-1 Roaster Stack Emission Parameter Values

Source Parameter	Stack Test Results October 14, 1993	Stack Test Results June 24, 1991
Arsenic Emission Rate Total (g/s)	0.306	0.167
Sulfur Dioxide Emission Rate Gas Phase (g/s)	315.7 - 752.3[1]	315.7 - 752.3[1]
Exit Gas Temperature (°K)	385.2	352.9
Exit Gas Velocity (m/s)	2.70	2.45
Volumetric Flow Rate (10^3 m^3/hr)	39.95	38.72

1. Estimated range corresponds to 30 - 65 (x 10^3 kg/day), not measured during stack test.

2.4 Meteorological Data

Meteorological data, provided by the Canadian Climate Centre of AES, included three years (1991, 1992, and 1993) of hourly surface meteorological data from the AES monitoring station at the Yellowknife Airport and three years of twice daily upper air soundings from the AES station at Fort Smith, which is the nearest upper air monitoring station. 1994 data was not yet available on disk from AES at that time. Surface data included hourly average air temperature, windspeed, wind direction, ceiling height, cloud cover, and daily snow cover. The twice daily upper air soundings give air temperature at elevations ranging from the ground surface (approx. 1000 millibars) up to about 3000 m. (700 millibars). This upper air data was used to calculate mixing heights. These data were processed through the PCRAMMET meteorological data processor to produce model input meteorological data sets.

2.5 Ambient Air Monitoring Data

Ambient air monitoring data summaries showing annual geometric mean and maximum daily levels of total arsenic measured at a monitoring station near the Yellowknife City Hall have been reviewed and used as a basis for comparison with model results. Ambient air sulfur dioxide monitoring data measured at the Yellowknife City Hall monitoring station have been reviewed and compared to sulfur dioxide modelling results. Hourly average sulfur dioxide monitoring data was provided for a portion of 1992, most of 1993 and 1994. The 1992 and 1993 data were compared to model estimates to evaluate operational performance of the model.

3.0 ATMOSPHERIC DISPERSION MODELLING

3.1 Model Selection

While atmospheric dispersion typically occurs by mixing due to turbulence in the planetary boundary mixed layer, it may at times be influenced by formation of a localized internal boundary layer which limits plume mixing and dispersion. Dispersion influenced by localized effects arises due to abrupt changes in surface roughness and/or temperature and often results in elevated ground level concentrations due either to plume trapping or fumigation. Plume trapping occurs when a stack discharges directly into an internal boundary layer which limits both the vertical rise of the plume and its ability to mix with a larger volume of air. Fumigation occurs when a stack initially discharges above a developing internal boundary layer but the plume, as it travels downwind, eventually intersects the internal boundary layer causing a portion of the plume involved to be mixed to ground level.

Of the two principal models considered here, the Industrial Source Complex (ISC2) Model generally models unimpeded mixing throughout the entire depth of the mixing layer, while the Shoreline Dispersion Model (SDM) incorporates internal boundary layer effects specific to the shoreline of a large water body.

1. Industrial Source Complex Model (ISC2)

   The Industrial Source Complex Model (ISC2) is a steady-state gaussian plume model which can be used to assess pollutant concentrations from a wide variety of sources associated with industrial complexes. This model can calculate ambient ground level concentrations of gas phase pollutants as well as settling and dry deposition of particulates, incorporate the effects of building wakes on ambient concentrations, and can handle limited terrain adjustments. This model was developed and tested by USEPA and has been continuously upgraded and refined over the years. At present it is one of the most thoroughly evaluated and most often recommended of USEPA's steady-state gaussian plume models for industrial sources.

2. Shoreline Dispersion Model (SDM)

   The Shoreline Dispersion Model (SDM) is a combination of two models which permits the analysis of both shoreline fumigation and nonfumigation conditions for sources near a shoreline. The Multiple Point Gaussian Dispersion

Algorithm with Terrain Adjustment (MPTER) model is used to calculate ground level concentrations of discharged contaminants under ordinary (nonfumigating) dispersion conditions. The Shoreline Fumigation Model (SFM) is used to calculate ground level contaminant concentrations under shoreline fumigation conditions. The SDM operates by evaluating each hour of meteorological input data to determine whether or not a Thermal Internal Boundary Layer (TIBL) is formed, TIBL thickness at the stack location, and whether or not the stack discharges to the atmosphere above or below the TIBL's upper boundary. Shoreline Fumigation, which can produce significantly elevated ambient ground level concentrations, only occurs when a TIBL forms and the stack emits above its upper boundary. Fumigation occurs at a location downwind from the stack where the plume intersects the TIBL upper boundary, which grows with distance downwind until it reaches the mixing height. Based on this evaluation the SDM uses either the MPTER or the SFM to calculate ambient concentrations for each hour of meteorological data.

Since TIBL's tend to occur during early summer when the land heats up while the water remains cool, by far the majority of hours modelled each year will be diagnosed as non-fumigating conditions. That means that most of the time the SDM will be selecting the MPTER model to compute ambient concentrations. Only at those rare times when the atmospheric conditions are just right (onshore winds > 2 m/s; daytime with A, B, or C stability over land; heat flux over land > 20 watts/m^2; stable air over water; and stack height > TIBL height) will SDM choose the SFM model. These conditions require a tall stack located rather close (< 1km) to a shoreline and would occur here for only a narrow range of wind directions (S and SSE). As the great majority of modelled conditions are non-fumigating and since the ISC2 is a more refined and up to date gaussian plume model than the MPTER, the ISC2 model was selected for use here.

3.2 ISCST2 Model Description

The Industrial Source Complex Short-Term (ISCST2) dispersion model used in this project is a restructured and reprogrammed version of the original ISC Short-Term model. It provides options to model simultaneous emissions from multiple sources and includes a wide range of emission source types typical for an industrial source complex. The basis of the model is the steady-state Gaussian plume equation, which is used with some modifications to model emissions from stacks which may experience the effects of aerodynamic downwash due to nearby buildings. Hourly meteorological data records are accepted and used to define the conditions for plume

rise, transport and diffusion. Either ambient concentration (ug/m^3) or particulate deposition (mg/m^2/hour) values can be calculated for each source and receptor combination for each hour of input meteorology, according to user-selected short-term averages. All modelling runs in this study were configured to compute ambient air concentrations.

ISCST2 models dry deposition based on the Dumbauld, et al (1976) deposition model. This model, which is an advanced version of the Cramer, et al (1972) deposition model, which incorporates use of reflection coefficients to account for the possibility that a fraction of the material initially deposited may be reflected back into the atmosphere.

3.3 Model Setup

Setting up data files for input to the ISCST2 requires consideration of model control parameters, source emissions, receptors, meteorology, and desired model output. For this effort, the ISCST2 model was configured to use rural dispersion parameter algorithms, 1 hr and 24 hr averaging times, and to output ground level ambient air concentrations at designated receptor locations. The regulatory default option, which makes use of a calms processor for windspeeds less than 1 m/s, and uses default exponent values for vertical windspeed and temperature gradient was also chosen. Roaster stack emission data, previously presented in Table 2-1, were used as source input data.

Receptor locations, points on the model grid where model output values are computed and recorded, were chosen to be 300 m apart in both the North-South and East-West directions. The model grid extends 6000 m to the east and west of the stack and 6000 m to the north and south, spanning an area 12 km by 12 km. In addition, the Yellowknife city hall located at (x= -1000 m, y= -5350 m) on the model grid is a receptor.

ISCST2 meteorological input data files were developed for each month of 1992 and 1993. The files require hourly average windspeed, wind direction, air temperature, Pasquill stability class, and mixing height values. Hourly mixing height values were computed from twice daily mixing height data computed from upper air sounding data provided by the Atmospheric Environment Service using PCRAMMET, a meteorological data preprocessor distributed by USEPA. The PCRAMMET fortran code required some modifications to accept the format and units of existing data inputs.

3.4 Baseline Modelling Results

Model runs were made at a mass emission rate of 65 x 10^3 kg/day for SO_2 and a mass emission rate of 26.8 kg/day for total Arsenic using existing values of stack height (45.7 m), exit gas temperature (112° C), and exit gas velocity (2.7 m/s) to determine maximum ground level SO_2 and total Arsenic concentrations. ISCST2 model runs were configured so that the 49 highest 1hr average and the 24 highest 24hr average SO_2 and total Arsenic concentrations computed anywhere on the model grid were tabulated for each monthly meteorological data set. The model grid used for these calculations is a square area (12 km x 12 km) that extends 6 km to the north, south, east, and west of the stack. Ground level concentrations are computed at 300m intervals across the entire grid.

Table 3-1 Predicted Baseline SO_2 Concentrations

Meteorological Data Set	Max 1 Hr. Avg. Conc. (ug/m^3)	Max 24 hr. Avg. Conc. (ug/m^3)
January 1993	2826	932
February 1993	3992	1454
March 1993	5963	1154
April 1993	4850	1388
May 1993	6238	1398
June 1993	4749	1243
July 1993	6461	1575
August 1993	5347	1282
September 1993	5143	1323
October 1993	4462	940
November 1993	3133	997
December 1993	3812	1223

Model results, shown above in Tables 3-1, predict ambient SO_2 concentrations that consistently exceed both the 1 hr and 24 hr average territorial SO_2 guidelines (450 ug/m^3 and 150 ug/m^3 respectively).

Model results, shown here in Tables 3-2, yield ambient total Arsenic concentrations that regularly exceed the 24 hr average Ontario guideline of 0.3 ug/m total Arsenic.

Table 3-2 Predicted Baseline Total Arsenic Concentrations

Meteorological Data Set	Max 1 Hr Avg. Conc. (ug/m^3)	Max 24 hr Avg. Conc. (ug/m^3)
January 1993	1.2	0.38
February 1993	1.6	0.60
March 1993	2.5	0.48
April 1993	2.0	0.57
May 1993	2.6	0.58
June 1993	2.0	0.51
July 1993	2.7	0.65
August 1993	2.2	0.53
September 1993	2.1	0.55
October 1993	1.8	0.39
November 1993	1.3	0.41
December 1993	1.6	0.50

Simulations for each month of 1993 were made for both total Arsenic and Sulfur dioxide emission. Two sets of simulations were made for each contaminant. In one set 24 hr average ambient air concentrations were computed for each day of 1993 at the Yellowknife City Hall. This output was meant to be compared with 1993 ambient air monitoring results. In the second set of simulations maximum 24 hr average values were determined for the entire grid of receptor locations. This model output was able to demonstrate areas where the highest concentrations could be found as

well as the magnitude of these concentration maxima. The results of simulations made are discussed in the next section.

Maximum 24 hr average total arsenic concentrations were estimated at a location near the Yellowknife City Hall for each month of 1993 and compared to ambient monitoring results reported at that location. These data are presented in Table 3-3. Both maximum daily and mean annual total Arsenic values predicted by the ISCST2 model were similar in magnitude but slightly lower than corresponding monitoring data values.

Table 3-3 Total Arsenic Concentrations Near Yellowknife City Hall

Concentration	ISCST2 Modelling Results for 1993	Ambient Air Monitoring Results for 1993
Maximum 24 hr Average Arsenic Concentration (ug/m^3)	0.140	0.251
Annual Geometric Mean Arsenic Concentration (ug/m^3)	0.009[1]	0.015

1. Arithmetic average, numerous zero values precluded geometric mean calculation.

Maximum 1 hr and 24 hr average sulfur dioxide concentrations were estimated at the Yellowknife City Hall for the months of March 1993 thru December 1993 and compared to ambient monitoring results for March 1993 thru February 1994. These data, which represent extreme maximum measured and model predicted concentrations, rather than the robust maxima described in section 4.1, are presented in Table 3-4. The maximum 1 hr, maximum 24 hr, and mean annual SO_2 concentrations predicted by the ISCST2 model were similar in magnitude but slightly lower than corresponding monitoring data values.

ISCST2 model simulations for total arsenic and sulfur dioxide were subsequently made using three months of meteorological data shown in section 4.2 to produce low model bias. While predicted concentrations for these three months did not exceed the territorial 1 hr standard for sulfur dioxide or the Ontario arsenic 24 hr standard for the

downtown Yellowknife area, exceedences were predicted and their approximate aerial extent was outlined. For arsenic, an area extending 3 km to the north and south of the roaster stack and 2.5 km to the east and west contained all 24 hr maximum values that exceeded the 0.3 ug/m^3 Ontario standard. The corresponding exceedence area for the 1 hr SO_2 NWT standard is circular in shape, centered on the stack, with a 5 km radius. Both of these areas, which are approximate and include extreme maxima, are shown in Figure 3-1.

Table 3-4 Sulfur Dioxide At Yellowknife City Hall

Concentration	ISCST2 Modelling Results for 1993	Ambient Air Monitoring Results Mar 1993 - Feb 1994
Maximum 1 hr Average SO_2 Concentration (ug/m^3)	1402.	1205.
Maximum 24 hr Average SO_2 Concentration (ug/m^3)	144.4	285.
Annual Geometric Mean SO_2 Concentration (ug/m^3)	9.6[1]	13

1. Arithmetic average, numerous zero values precluded geometric mean calculation.

4.0 MODEL EVALUATION

4.1 Evaluation Methodology

This ISCST2 model application has been subjected to a screening test to evaluate the extent to which it meets minimum standards for operational performance. Operational performance is a measure the model's ability to estimate concentration statistics most directly used for regulatory purposes. For pollutants such as SO_2 and total Arsenic, for which short-term ambient air standards exist, the statistic of interest is the magnitude of the highest ambient concentrations occurring on the model grid. As the extent of atmospheric dispersion and mixing of Roaster stack SO_2 and total Arsenic emissions are identical, their concentration maxima occur at the same time and place.

As the highest concentrations can be subject to extreme variations, a robust test statistic is calculated that represents a "smoothed" estimate of the highest concentration. This robust estimate of the highest concentration (RHC), preferable because of its stability, is used to evaluate model performance. The RHC is computed for corresponding monitoring and model predicted monthly data sets using the 25 highest concentrations identified within each data set. The robust estimate of highest concentration is based on a tail exponential fit to the upper end of the concentration cumulative probability distribution.

The robust estimator of the highest value is related to the mean and standard deviation of the 25 highest values in each data set. Increases in their central location and spread tends to increase the magnitude of the highest value within the 25 highest concentrations. The robust highest value in effect is a direct measurable result of the composite impact of the central location of the highest values and their spread about that central location.

The fractional bias, used here as a performance measure, is calculated to compare observed ambient air and model predicted values of the test statistic, RHC. It is the ratio of the difference (RHC_{obs} - RHC_{pred}) to the average of the RHC of the observed (monitoring data) and model predicted highest 25 values for corresponding monthly data sets. The fractional bias is used as the basic measure of performance in this evaluation because it is symmetrical and bounded. Values for the fractional bias range between -2.0 (extreme overprediction) and +2.0 (extreme underprediction). Values of the fractional bias that are equal to -0.67 are equivalent to overpredictions by a factor-of-two, while values that are equal to +0.67 are equivalent to an underprediction by a factor-of-two.

4.2 Comparison of Modelling and Monitoring Results

Robust highest concentrations (RHC) for 14 months of ambient SO_2 monitoring data (Yellowknife City Hall Monitoring Station) are compared in Table 4-1 with corresponding model simulated values. These model predictions, computed with a sulfur dioxide mass emission rate of 30 x 10^3 kg/day, were found to have a fractional bias less than the maximum permissable value of 0.67 for 12 of the 14 months tested. The fractional bias, a measure of deviation from complete model accuracy, was found to be zero for three of the 14 months. These three monthly meteorological data sets were then used to make predictions of compliance with territorial air quality guidelines.

Table 4-1 Model Performance Evaluation Based on Observed and Predicted 1 hr Average SO_2 Concentrations (ug/m^3)

Meteorological Data Set	Robust Highest Concentration (OBS.)	Robust Highest Concentration (PRED.)	Fractional Bias
August 1992	342	579	-0.51
September 1992	947	797	0.17
October 1992	500	443	0.12
November 1992	1307	1301	0.004
March 1993	717	811	-0.12
April 1993	592	1028	-0.54
May 1993	421	718	-0.52
June 1993	530	874	-0.49
July 1993	844	848	-0.004
August 1993	1000	994	0.006
September 1993	348	815	-0.80
October 1993	478	1137	-0.82
November 1993	926	1447	-0.44
December 1993	685	1203	-0.55

5.0 SENSITIVITY ANALYSIS

5.1 Overview

The magnitude of ambient ground level SO_2 and total Arsenic concentrations are influenced by the mass emission rates of SO_2 and total Arsenic as well as by atmospheric dispersion. The sensitivity of ambient ground level concentrations to variations in mass emission rate and atmospheric dispersion is evaluated for roaster stack SO_2 emissions. While ambient ground level total Arsenic concentrations are also sensitive to variations in these parameters, only the effects on SO_2 were calculated.

The extent to which stack emissions are mixed and diluted by atmospheric dispersion is influenced by both meteorological factors and stack discharge parameters. This effort is aimed at characterizing the influence of both the SO_2 mass emission rate and stack discharge parameters (stack height, exit gas velocity, and exit gas temperature) on ground level concentrations of SO_2.

Model runs were made over a wide range of values of mass emission rate, stack height, exit gas temperature, and exit gas velocity to determine the effect these parameters have on maximum ground level SO_2 concentrations. A series of model runs was made with SO_2 mass emission rate reduced from its maximum value of 65 x 10^3 kg/day by 25%, 50%, 75%, 90%, and 95%. Likewise, model runs were made with stack discharge parameter values individually varied by 25%, 50%, 75%, and 100%. This series of model runs was repeated with an SO_2 mass emission rate of 35 x 10^3 kg/day.

ISCST2 model runs were configured so that the 49 highest 1hr average SO_2 concentrations computed anywhere on the model grid were tabulated for each monthly meteorological data set. Monthly meteorological data sets that showed essentially zero model bias (November 1992, July 1993, and August 1993) were chosen for use in each sequence of sensitivity analysis model runs. The model grid used for these runs is a square area (12 km x 12 km) that extends 6 km to the north, south, east, and west of the stack. Ground level concentrations are computed at 300m intervals across the entire grid.

5.2 Effects of Mass Emission Rate Variations

The SO_2 mass emission rate was varied with all other parameters held constant to determine its impact on ground level SO_2 concentrations. The objective was to identify a range of mass emission rates which would produce ambient SO_2 concentrations that did not exceed the 1 hr average territorial SO_2 guideline value of 450 ug/m^3. The results of these model runs are presented in Table 5-1.

Table 5-1 Effect of SO_2 Mass Emission Rate Variations on Ambient 1 hr Average SO_2 Concentrations (ug/m^3)

Mass Emission Rate (g/s)	Percent Reduction	Max 1 hr Avg. Conc.(ug/m^3) Nov 92	Max 1 hr Avg. Conc.(ug/m^3) Jul 93	Max 1 hr Avg. Conc.(ug/m^3) Aug 93
752.3[1]	0	3304	6461	5347
564.2	25	2478	4846	4010
376.2	50	1652	3231	2674
188.1	75	826	1616	1337
75.2	90	330	646	535
37.6	95	165	323	267

1. 752.3 g/s equals 65 x 10^3 kg/day

As shown in Table 5-1, a reduction in the SO_2 mass emission rate of nearly 95 percent is required to reduce maximum ambient 1 hr average SO_2 concentrations to levels that do not exceed the territorial air quality guideline of 450 ug/m^3.

5.3 Effects of Variations in Stack Discharge Parameters

Stack discharge parameters (stack height, exit gas velocity, and exit gas temperature) were varied individually in model runs made using the three low bias monthly meteorological data sets. The objective was to identify a range of parameter values which would yield ambient SO_2 concentrations that did not exceed the 1 hr territorial

SO_2 guideline of 450 ug/m^3. One set of model runs was made at a mass emission rate of 65 x 10^3 kg/day SO_2 and another set was made at a mass emission rate of 35 x 10^3 kg/day SO_2 .

5.3.1 Stack Discharge Effects at 65 Tonnes/Day SO_2

The effects of stack height increases of up to 100% of the existing height reduce the maximum ambient SO_2 concentrations by 40 - 45 %, but leave them well above territorial guidelines. This effect is shown in Table 5-2.

Effects of exit gas temperature increases, shown in Table 5-3, up to 100% of existing temperature only reduce maximum ambient SO_2 concentrations by 30% in November and by 50 - 60 % during the warmer months. Ambient concentrations exceed territorial guideline values for all three months.

Table 5-2 Stack Height Effect on Ambient 1 hr Average SO_2 Concentrations (ug/m^3)

Stack Height (m)	Percent Variation	Max 1 hr Avg. Conc.(ug/m^3) Nov 92	Max 1 hr Avg. Conc.(ug/m^3) Jul 93	Max 1 hr Avg. Conc.(ug/m^3) Aug 93
45.7	0	3304[1]	6461[1]	5347[1]
57.13	+ 25	3157	4514	5116
68.55	+ 50	2387	3993	5005
79.88	+ 75	2061	3799	3642
91.40	+ 100	1833	3635	3277

1. At mass emission rate of 65 x 10^3 kg/day SO_2.

Reductions in stack diameter and the corresponding increase in exit gas velocity, shown in Table 5-4, produce no reduction in the maximum ambient SO_2 concentration and demonstrate the fact that plume rise is buoyancy flux dominated. Ambient air SO_2 concentrations remain well above territorial guideline value for all three months.

Table 5-3 Effect of Exit Gas Temperature Variations on Ambient 1 hr Average SO_2 Concentrations (ug/m^3)

Exit Gas Temperature (C)	Percent Variation	Max 1 hr Avg. Conc.(ug/m^3) Nov 92	Max 1 hr Avg. Conc.(ug/m^3) Jul 93	Max 1 hr Avg. Conc.(ug/m^3) Aug 93
112	0	3304[1]	6461[1]	5347[1]
140	+ 25	3282	4124	3986
168	+ 50	3279	3953	3411
196	+ 75	2451	3899	2966
224	+ 100	2417	2719	2782

1. At mass emission rate of 65 x 10^3 kg/day SO_2.

Table 5-4 Stack Diameter and Exit Gas Velocity Effects on Ambient 1 hr Avg. SO_2 Concentrations (ug/m^3)

Stack Diameter (m)	Percent Reduction	Exit Gas Velocity (m/s)	Max 1 hr Avg. Conc.(ug/m^3) Nov 92	Max 1 hr Avg. Conc.(ug/m^3) Jul 93	Max 1 hr Avg. Conc.(ug/m^3) Aug 93
2.7	0	2.7	3304[1]	6461	5347
2.03	25	4.8	3287	6461	5346
1.35	50	10.8	3280	6461	5347
1.00	63	19.8	3280	6460	5346
0.68	75	42.6	3280	6461	5347

1. At mass emission rate of 65 x 10^3 kg/day SO_2.

5.3.2 Stack Discharge Effects at 35 Tonnes/Day SO_2

The effects of stack height increases, shown in Table 5-5, are similar to those shown in Table 5-2 in that stack height increases up to 100% of the existing height only reduce the maximum ambient SO_2 concentrations by 40 - 45 % leaving them above territorial guidelines.

Increased exit gas temperature, shown in Table 5-6, reduce maximum ambient SO_2 concentrations by 30% in November and by 50 - 60 % during July and August. Maximum ambient concentrations remain well above the territorial guideline value.

Table 5-5 Stack Height Effect on Ambient 1 hr Average SO_2 Concentrations (ug/m^3)

Stack Height (m)	Percent Variation	Max 1 hr Avg. Conc.(ug/m^3) Nov 92	Max 1 hr Avg. Conc.(ug/m^3) Jul 93	Max 1 hr Avg. Conc.(ug/m^3) Aug 93
45.7	0	1779[1]	3479[1]	2879[1]
57.13	+ 25	1670	2431	2755
68.55	+ 50	1285	2151	2695
79.88	+ 75	1110	2046	1961
91.40	+ 100	987	1957	1764

1. At mass emission rate of 35 x 10^3 kg/day SO_2.

Reductions in stack diameter and the corresponding increase in exit gas velocity, shown in Table 5-7, do not reduce ambient SO_2 concentrations which remain well above the territorial guideline value.

Table 5-6 Effect of Exit Gas Temperature Variations on Ambient 1 hr Average SO_2 Concentrations (ug/m^3)

Exit Gas Temperature (C)	Percent Variation	Max 1 hr Avg. Conc.(ug/m^3) Nov 92	Max 1 hr Avg. Conc.(ug/m^3) Jul 93	Max 1 hr Avg. Conc.(ug/m^3) Aug 93
112	0	1779[1]	3479[1]	2879[1]
140	+ 25	1767	2221	2146
168	+ 50	1766	2129	1837
196	+ 75	1320	2029	1597
224	+ 100	1301	1464	1498

1. At mass emission rate of 35 x 10^3 kg/day SO_2.

Table 5-7 Stack Diameter and Exit Gas Velocity Effects on Ambient 1 hr Avg. SO_2 Concentrations (ug/m^3)

Stack Diameter (m)	Percent Reduction	Exit Gas Velocity (m/s)	Max 1 hr Avg. Conc.(ug/m^3) Nov 92	Max 1 hr Avg. Conc.(ug/m^3) Jul 93	Max 1 hr Avg. Conc.(ug/m^3) Aug 93
2.7	0	2.7	1779[1]	3479[1]	2879[1]
2.03	25	4.8	1770	3479	2878
1.35	50	10.8	1766	3479	2879
1.00	63	19.8	1766	3478	2878
0.68	75	42.6	1766	3479	2879

1. At mass emission rate of 35×10^3 kg/day SO_2.

5.4 Combined Effects

Model results, shown here in Tables 5-8 and 5-9, were made with all three stack discharge parameters set jointly to significantly increased values (stack ht. = 122 m, EGT = 200° C, and EGVel. = 24.2 m/s). Table 5-8 presents the combined results of these effects at an SO_2 emission rate of 65 x 10^3 kg/day. Table 5-9 presents the combined results of these effects at an SO_2 emission rate of 35 x 10^3 kg/day. Even at these significantly increased stack discharge parameter values, exceedences of the 1 hr and 24 hr SO_2 guideline values were not eliminated at either mass emission rate. While maximum ground level SO_2 concentrations were reduced by increasing these parameter values, the effect was not enough to eliminate exceedences. The 1 hr guideline concentration was exceeded for each of the ten months at both mass emission rates modeled. Likewise, the 24 hr guideline concentration was exceeded for eight of the ten months at the maximum emission rate and for five of the ten months at the lower mass emission rate.

Table 5-8 SO_2 Concentrations at Jointly Increased Stack Discharge Parameter Values

Meteorological Data Set	Max 1 Hr Avg. Conc. (ug/m^3)	Max 24 hr Avg. Conc. (ug/m^3)
March 1993	1597[1]	287[1]
April 1993	1775	299
May 1993	1811	524
June 1993	2014	272
July 1993	2116	491
August 1993	1910	334
September 1993	1644	276
October 1993	1320	241
November 1993	883	147
December 1993	853	127

1. Mass emission rate of 65 x 10^3 kg/day SO_2.

Table 5-9 SO_2 Concentrations at Jointly Increased Stack Discharge Parameter Values

Meteorological Data Set	Max 1 Hr Avg. Conc. (ug/m^3)	Max 24 hr Avg. Conc. (ug/m^3)
March 1993	860[1]	155[1]
April 1993	956	161
May 1993	975	282
June 1993	1084	146
July 1993	1139	264
August 1993	1028	180
September 1993	885	149
October 1993	711	130
November 1993	475	79
December 1993	459	68

1. Mass emission rate of 35 x 10^3 kg/day SO_2.

These model results demonstrate that adjustments to dispersion alone will not eliminate exceedences of territorial ambient air quality guidelines. To achieve the ambient concentration reductions required to meet 1 hr average territorial SO_2 guidelines, it will be necessary to reduce the mass emission rate of SO_2.

6.0 CONCLUSIONS

ISCST2 modelling results compared relatively well with fourteen months of ambient SO_2 monitoring data provided. Three months of meteorological data produced effectively zero bias model results, and were therefore used to conduct the sensitivity analysis. The anticipated effects of shoreline fumigation, which would cause the ISCST2 to underpredict ground level concentrations, were not experienced perhaps due to the location of the City Hall monitoring station. During onshore flows, this monitoring station is upwind of the stack, so that even if fumigation were occurring downwind of the stack, it would not be detected at the monitoring station.

Baseline model runs for SO_2 showed that territorial 1 hr and 24 hr average ambient SO_2 guideline values were regularly exceeded and that the areal extent of these exceedences could be approximated as a circle, centered at the roaster stack, with a 5 km radius.

Baseline model runs for total Arsenic emissions showed that the Ontario provincial 24 hr average ambient guideline value was regularly exceeded in an area, shaped like an ellipse, that extends approximately 3 km to the north and south of the roaster stack and 2.5 km to the east and west.

As the mass emission rate of SO_2 is a very important parameter in the control of ground level SO_2 concentrations, it is recommended that the mass emission rate of sulfur dioxide be checked regularly through installation of instack continuous monitoring devices or by mass balance computations. Mass inputs to the roaster (from the sulfide concentrate feed and perhaps the spray water used in the second stage) minus the sum of mass lost via the main roaster discharge, removal by ESPs, and removal by the Baghouse should equal the mass emitted to the atmosphere. These mass balance computations could serve as a check on stack test results, particularly if samples were taken during the time of the stack tests.

An analysis of the sensitivity of ambient ground level SO_2 concentrations to variations in mass emission rate and atmospheric dispersion showed that even significant increases in stack discharge parameter (stack height, exit gas temperature, and exit gas velocity) values did not reduce ambient SO_2 concentrations to levels below territorial 1 hr and 24 hr average guideline values at either of the mass emission rates tested. While all exceedances were not eliminated until the mass emission rate of SO_2 was reduced by 90 to 95 percent from its maximum value, several monthly 1 hr averages were reduced to levels below the acceptable federal level at the 34 x 10^3 kg/day mass emission rate when stack discharge parameters were optimized.

Although it is not likely that all exceedances of the territorial standard will be eliminated by optimizing stack discharge parameter values operating at a mass emission rate of 35 x 10^3 kg/day, this combination of efforts may produce results that are reasonably close. It is therefore recommended that additional model runs be made using adjusted stack height, exit gas temperature, and sulfur dioxide mass emission rate values determined by Royal Oak to be possible to achieve. Ambient maxima produced by these model runs will be representative of actually achievable maximum ambient SO_2 values.

7.0 REFERENCES

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