18t" International Mining Congress and Exhibition of Turkey-IMCET 2003, © 2003, ISBN 975-395-605-3

Estimation of Fugitive Dust Impacts of Open-Pit Mines on Local Air Quality - A Case Study: Bellavista Gold Mine, Costa Rica

C. B. Arpacıoğlu & C. Er
SRK Consulting, Ankara, Turkey

ABSTRACT: Fugitive dust impacts of Bellavista open-pit gold mine located in Costa Rica was investigated. The fugitive dust emissions from the gold mine were identified and then quantified using emission factors. The impacts of the fugitive dust emissions were estimated by means of FDM air quality dispersion model developed by the USEPA. TSP and PM|„ concentration estimates obtained from the FDM model were compared with the Costa Rican and World Bank air quality standards. The fugitive dust impacts from the gold mine were found to have relatively insignificant impact in a confined area centered around the mine site.

I INTRODUCTION

Dust is a generic term that describes particulate matters suspended in the atmosphere. It does not make any distinction between the size, shape, and chemical composition of the particulate matters. Fugitive dust refers to dust that is derived from nonpoint sources and does not have an easily defined source. It is formed when particulate matters become airborne due to turbulent action of the wind, mechanical disturbance of fine materials, or release of gaseous emissions laden with particulate matters in an unconfined manner.

There are various dust generating activities and processes in the mining industry. Sources such as material storage silos, process boilers and heaters, onsite power generators etc. are the major point sources in the mining industry. The exhaust gases emanating from the mining equipment and other vehicles operated within the mine site are mobile sources of particulate matters. But the most predominant sources of particulates in the mining industry are the fugitive dust sources. Fugitive sources comprise earth moving and material handling operations, crushing, screening, milling, blasting and drilling, haul roads, and wind erosion of exposed surfaces. Fugitive sources are more difficult to control as compared to point sources.

Mine dust can cause serious nuisance and aesthetic deterioration in the surrounding environment and communities. Fortunately due to relatively large particulate matter sizes associated with the mining emissions and the relatively short release height of the pollutants, such negative impacts are usually confined in relatively small areas. Within these areas of impact, fugitive dust may result in damage to the vegetation and agriculture. The deposited particulate matter may block the plant leaf stomata hence inhibit gas exchange, or smother the plant leaf surfaces reducing photosynthesis levels (Environment Australia, 1998).

Besides the impacts on vegetation, health effects of particulates on mine personnel and public may also be significant. The inhalable fraction of dust (i.e. PM|o, particulate matters of aerodynamic diameters less than I0 |im) passes through the nose and mouth, and is easily deposited in the trachea and bronchial section of the lungs. Respirable dust (i.e. PM_{25}, particulate matters less than 2.5 u.m diameter) penetrates unciliated airways in human lungs, and lodges in the alveolar region (ISO, 1995). Depending on the chemical and physical characteristics of the particulate matters, there may be significant health effects. Dust containing heavy metals, certain silica and asbestos forms are known to have increased adverse health effects.

It is important to identify and quantify the fugitive dust emissions and impacts associated with mining operations early in the planning stage. Such an approach to mine fugitive dust emissions may help control the dust emissions and improve environmental performance of the proposed mine. Emission and air dispersion models are widely used to estimate the fugitive dust emissions and impacts.

The current study focuses on the investigation of fugitive dust impacts of an open-pit gold mine in Costa Rica. The fugitive dust emissions from the proposed mine were estimated by means of emission factors. The subsequent atmospheric dispersion of particulate matter was investigated by means of a numerical model, FDM, developed by the US Environmental Protection AgencyTUSEPA).

2 PROJECT DESCRIPTION

Bellavista gold mine is situated in the Puntarenas Province of Costa Rica (Fig. 1). The mine site is located approximately 3 km northeast of the town of Miramar. The fugitive dust impacts of the mine are of significance for the residents of Miramar and the forested area northeast of the mine site.

Bellavista gold mine has total mineable reserves of 11.2 million tonnes with an estimated project life of 10 years. Ore production will be approximately 1.6 million tonnes per year at its maximum capacity. Gold ore will be mined by conventional open-pit methods utilizing mid-size earth moving equipment. Approximately 2.2 million tonnes of waste rock per year will be excavated during the open-pit mining.

Blasting will be conducted daily in the mine pit. The broken waste rock and ore will be hauled using 50-tonne capacity haul trucks. The waste rock will be hauled to a stockpile area located approximately one km northwest of the open-pit (Fig.2). The ore will be hauled to the stockpile on the south end of the pit, from where it will be loaded into primary crushers.

Transport of the ore between the crushers will be accomplished via conveyors. Lime will be added to the ore before the secondary crusher to prevent crusher plug-ups and screen blinding. Following the tertiary crushers, ore will be placed into either low-grade or high-grade ore bins. From the ore bin, high-grade ore will be transferred to the milling plant for further size reduction. Low-grade ore will be transferred to the agglomerator where high-grade ore and cement will be added to form stable agglomerates. The ore agglomerates will be transported to the leach pad via overland conveyors feeding a line of standard portable "grasshopper" conveyors to a portable long-leg conveyor and a radial stacking conveyor

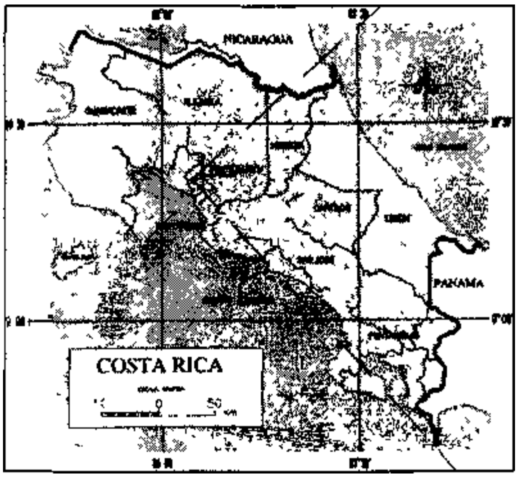

Figure 1. Location of the Proposed Bellavista Gold Mine

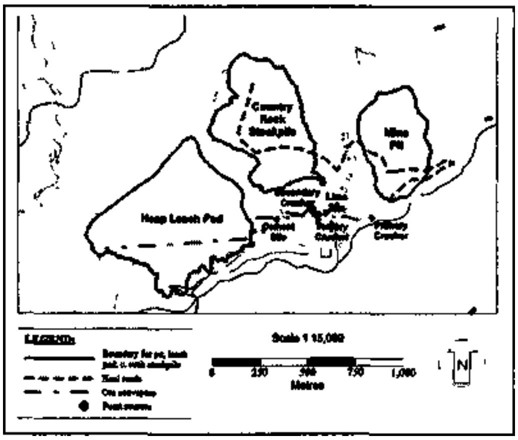

Figure-2. Mine Site Layout and Major Dust Emission Sources

Cyanide solution pumped from the carbon adsorption-desorption-recovery (ADR) facility will be applied onto the leach pad. The collected pregnant leach solution will be sent to the ADR facility to recover precious metals from the pregnant solution. The gold in the pregnant solution will be removed by carbon in adsorption columns. The loaded carbon columns will be stripped of its gold content using a heated caustic-cyanide solution. The caustic-cyanide solution will be heated using diesel-fired hot water boiler. The gold will then be plated out in an electrowinning cell. The gold plating from the cathodes of the electrowinning cell will be refined into doré using diesel-fired pot furnace. The spent carbon from the columns will be regenerated in a diesel-fired reactivation furnace. Power requirements of the mine will be met by seven 1000 kW diesel-fired generators.

3 DUST EMISSIONS AND CONTROLS

Particulate matter emissions will take place during the construction, operation, and closure phases of the mine project. The emissions will occur in varying particulate size ranges. The two size ranges considered in this study are the inhalable (PM_{10}) and total suspended particulate (TSP) matters. TSP roughly covers the range of particles with aerodynamic diameters less than 45 um. TSP inherently encompasses the inhalable and respirable fractions, as well as the coarser fractions. The coarse fraction of TSP has more of an aesthetic significance than human health significance. The respirable fraction ($PM_{2.5}$) of particulate matter was not considered in this study since mine dust mostly consists of the coarse fractions.

3.1 Construction Phase Emission Sources

During the construction phase of the project, which will last about a year, particulate matter will be released from the point, mobile, and fugitive sources. In general, the nature and spatial orientation of the emissions during the construction phase will be similar to the operational phase emissions. The construction activity and pollutant emission rates will be less than the full-scale mining operation rates. Therefore, construction phase emissions were not assessed in detail. It is conservatively assumed that construction phase air emissions and related impacts would be at most equivalent to the operational phase emissions and impacts.

3.2 Operation Phase Emission Sources

The emission sources during the mine operation will be from point, mobile, and fugitive sources. The major point sources will be:

- Power generators;
- Desorption column boiler;
- Doré furnace;
- Carbon regeneration furnace;
- Cement and lime silos;

The major fugitive dust sources will be:

- Primary, secondary, tertiary crushers/screens;
- Haul and various mine roads;
- Transfer points on the ore conveyors.
- Drilling and blasting in the mine pit;
- Materials handling (loading/unloading, bulldozing etc. in/on open-pit, waste rock stockpile, leach pad, coarse ore stockpile, and various other material aggregates);
- Wind erosion of the exposed surfaces (i.e. leach pad, coarse ore stockpile, waste rock stockpile, etc.)

Major mobile sources of air contaminants during the mine operation will be several 50-tonne haul trucks, front-end loaders, bulldozers, backhoes, utility trucks and pickups.

3.3 Closure Phase Emission Sources

The emission sources during the closure phase will be reclamation activities. The plant buildings will be demolished and the mine site will be graded and revegetated. The particulate matter emissions will be due to surface activities and mobile sources. The closure phase emissions will be relatively insignificant and will have short duration.

3.4 Emission Control Measures

The proposed mine will implement several mitigation measures to reduce air emissions. The proposed emission control measures and expected control efficiencies are listed in Table 1. Dust from the haul roads, one of the major sources of fugitive dust, will be controlled using water trucks. During the dry periods, the roads will be kept wet to reduce particulate matter emissions. The pollution controls listed in Table 1 achieve efficiencies as high as 99.5%, when fully implemented.

Table 1 : Air Pollution Control Measures.

Source	Control	Efficiency
Crushes s	High pressure water sprays	90.0 %
Haul loads	Dust suppression using water	90.0 %
Conveyors	Covers	85.0 %
Silos	Dust collector	99.5 %

3.5 Emission Rate Estimates

Particulate matter emission rates for the operation phase were estimated using emission factors published by the US EPA (IJSEPA, 1995a). Emission factors are pollutant quantity estimates that relate pollutant generation rate to mine activity levels (e.g. grams of pollutant per tonnes of material transferred or produced). But for some fugitive dust sources, such as material handling operations (e.g. bulldozing, unloading etc.) or wind erosion such a direct relation may prove difficult to establish. For such fugitive sources, meteorological conditions (e.g. wind speed, precipitation) and physical properties of materials (e.g. silt and moisture content) are important and needs to be addressed to estimate emissions.

Annual operation phase fugitive dust emission estimates for the Bellavista gold mine are given in Table 2. These values reflect the emissions resulting after the pollution controls listed in Table 1 are implemented. The overall mine TSP emissions are estimated to be 114 tonnes/year. PMm emissions (62 tonnes) constitute 54% of TSP emissions. Fugitive sources constitute 82% and 66% of overall mine TSP and PM|0 emissions, respectively.

Table *2:* Annual Fugitive Dust Emission Estimates.

Source	Type'	PM|„ (kg/year)	TSP (kg/year)
Cement Silo	P	10	10
Lime Silo	P	2	2
Combustion Sources	P	9.215	9.215
Crushers & Screens	F	7.524	19.627
Conveyors	F	8.750	21.876
Haul Roads	F	6,005	16.681
Pit Operations	F	1.621	6,516
Blasting & Drilling	F	13.188	16.924
Waste Rock Dump Operations	F	492	2,078
Leach Pad Operations	F	118	663
Ore Stockpile Operations	F	608	2.410
Wind Erosion	F	2.219	6,163
Mobile Sources	M	11,794	11.794
Point Sources Total		*9.226*	*9.227*
Fugitive Source. Total*		*40.525*	*92,9M*
Overall Mine Emissions		*61,545*	*11.1959*

P- Point source; F- Fugitive source; M: Mobile source.

The particulate matter emissions due to blasting and drilling to be conducted in the open-pit constitute 15-20% of the overall mine emissions. Although, these emissions constitute a major portion of the overall emissions, the amount that would be dispersed into the surrounding environment will be less due lo retention of the open-pit. To account for pit retention effects, Equation 1 is used to estimate the escape fraction of the fugitive dust generated within the pit confines (USEPA, 1995b):

$$\varepsilon_i = \frac{1}{\left(1+\frac{V_g}{\alpha \cdot U_i}\right)} \qquad (1)$$

where;

U, = approach wind speed at 10 m (m/s)
V_g = gravitational settling velocity (m/s)
a = proportionality constant (0.029)
e, = escape fraction for size class i

The particulate matter emission rates presented in Table 2 were estimated by assuming the maximum possible mine activity rates. In this manner, worst-case emission rates were obtained. The mine operational schedules (e.g. holidays, shift hours, heavy rain days), as well as the meteorological conditions (i.e. wind speed, precipitation) were taken into account in estimating the emission rates. The particulate matter emission rates were obtained from the uncontrolled emission rates by applying the control efficiencies listed in Table 1. The uncontrolled overall mine TSP and PM|<, emissions are estimated to be 494 tonnes and 206 tonnes per year, respectively.

4 REGIONAL METEOROLOGY

Detailed meteorological information about the mine area is necessary to estimate particulate matter emission rates and atmospheric dispersion of the emissions. Air quality dispersion models usually require hourly meteorological data covering at least one-year period. In this study, data for the following parameters were used:

- Wind speed,
- Wind direction,
- Ambient temperature,
- Rainfall amount,
- Atmospheric stability class.

Wind speed, wind direction, ambient temperature, and rainfall amounts are measured parameters, whereas, atmospheric stability class is a derived parameter. Atmospheric stability is a measure of the dispersal potential of the atmosphere. There are various methods for estimating the atmospheric stability. Meteorological Processor for Regulatory Models (MPRM). developed by the USEPA (USEPA, 1996) was used to process measured hourly meteorological data to estimate the atmospheric stability.

Daily rainfall amount and number of days with rainfall are required for particulate matter emission estimation. Days with rainfall amount greater than 0.25 mm are considered to be wet days where fugitive dust generation is zero. For fugitive dust generation, a threshold wind speed criterion of 5.4 m/s is also applicable. Time periods with wind speeds higher than this criterion have higher fugitive dust generation potential.

The meteorological data required for emission and dispersion estimates was obtained from a newly established on-site meteorological station. The on-site station did not a have complete year's worth of data, and therefore, was augmented by the Puntarenas Station 18 km southwest of the mine site.

The predominant wind directions at the mine site are north-northeast (NNE) and northeast (NE). These directions are in agreement with the local topography. Stream channels for the Rio Rastra and the Rio Ciruelas lie in a southwest (SW) to northeast (NE) alignment. Annual average wind speed is 3.0 m/s. The frequency of hourly wind speeds exceeding 5.4 m/s is approximately 16%. The combined occurrence frequency of wind speeds higher than 5.4 m/s and daily precipitation amounts less than 0.25 mm is 12%. This indicates that most of the high wind speed events coincide with the dry periods. Such conditions are conducive to high fugitive dust generation.

The average monthly rainfall is given in Figure 3. The rainfall pattern observed at the mine site is defined by the influence of the Inter-tropical Convergence Zone (ITCZ), northeastern trade winds, and polar air masses. During the dry season observed between the months of December and April, the ITCZ is located south of Costa Rica and the polar air masses dominate the region. The polar air masses lose their moisture content while ascending the Tilaran Mountain Range on the Caribbean side. While descending the Tilaran Mountain Range on the Pacific side the polar air masses become cool and dry. The dry season ends when the ITCZ returns to 10° North latitude. The average annual rainfall for the region is approximately 2950 mm (Herrera, 1998). The highest rainfall occurs in the months of August, September and October.

5 AIR QUALITY REGULATIONS

Costa Rican general health law prohibits all actions, practices or operations that deteriorate the natural environment or alter the composition or intrinsic characteristics of its basic elements, especially air.

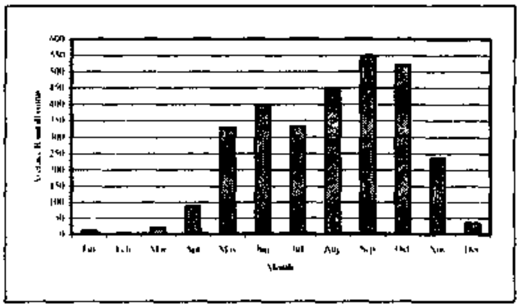

Figure-.V Average Monthly Rainfall

At present, few Costa Rican ambient air quality standards are available. In the absence of Costa Rican standards, international World Bank standards are used to evaluate the impacts of the proposed mining operation. The Costa Rican and World Bank ambient particulate matter standards are given in Table 3.

Table 3' Ambient Particulate Matter Standards.

Source	PM„, (lig/m')	TSP (Mg/m^1)	Averaging Period
Costa Rican	85	150	Annual
World Bank	50	80	Annual
World Bank	150	100	Daily

6 ESTIMATION OF FUGITIVE DUST IMPACTS

In order to determine the impacts from a facility on local air quality, an air dispersion modeling study has to be conducted. This study is accomplished by use of mathematical models that relate emission rates to ambient air concentrations. Air quality models use meteorological data, emission rate and source data, and topographical and surface cover data to estimate ground-level pollutant concentrations. For the current study, impacts of the particulate matter emissions from the mine operations were estimated using Fugitive Dust Model (FDM) developed by the US EPA (USEPA, 1992). The pollutant concentrations estimated using the air dispersion model are compared with the established national/international air quality standards.

6. / *Description of the FDM*

FDM is a computerized air quality model specifically designed for computing concentration and deposition impacts from fugitive dust sources. The sources may be point, line, or area sources. Each source type may be treated as virtual volume source with an initial vertical mixed extent. The model has not been designed to compute the impacts of buoyant point sources, thus it has no plume-rise algorithm. Particulate matter emissions for each pollutant source are apportioned into a series of size classes. A gravitational settling velocity and a deposition velocity are calculated by FDM for each size class. Particulate matter concentrations and depositions are then computed at receptor locations.

Particulate matter mass depletion is achieved by the process of dry deposition. FDM accounts for deposition through two parameters: the gravitational settling velocity and the deposition velocity. As the name implies, the gravitational settling velocity accounts for removal of particulate matter from the atmosphere due to gravity. Since only the larger particles have sufficient mass to overcome turbulent eddies, this mechanism is significant only for the larger size ranges (e.g. particles greater than 30 (im). The deposition velocity accounts for removal of particles by all methods, including turbulent motion, which brings the particulate matters into contact with a surface and allows it to be removed by impaction or adsorption at the surface. It is known that for smaller particles the deposition velocity is significantly different from the gravitational settling velocity, while for large particles they are roughly the same. In the FDM, the emission rate is divided into a number of particles size classes. Each of the classes has a unique gravitational settling velocity and deposition velocity. The method used by the model to compute the gravitational settling velocities and deposition velocities is modeled after the work of Sehmel and Hodgson (1978). Key variables to the method are the roughness, height and the friction velocity.

6.2 *Modeling Methodology*

Emission sources discussed in Table 2 were modeled as point, area, and line sources. The modeled sources are also presented in Figure 2. Lime silo, cement silo, crushers, and ore conveyor transfer points were modeled as point sources. Haul roads were modeled as line sources, made up of 30 individual segments. The emissions occurring within the boundaries of the mine pit, country rock stockpile, heap leach pad, and coarse ore stockpile were modeled as area sources. All of the pollutant sources were modeled as virtual volume sources with emissions distributed equally within the first 10 m above the ground surface. This height is consistent with the general mine operations where emissions are initially distributed vertically due to turbulence caused by surface irregularities present at the mine sites.

The particulate matter emissions from each source were varied hourly. The emission rates were adjusted according to shift hours, workdays, rainy days, and high wind speed events. Each emission source was represented by 8760 hours (24 hours x 365 days) of emission rate. The particulate matter emissions were segregated into two major particle size class categories, namely PM|(> and TSP (PM_{45}). Additional particle size classes (i.e. 2.5, 5, 15 and 30

|iin) were included in the settling and deposition velocity calculations, but their concentrations were not estimated since there are no established international standards.

The project site has a complex topography with elevations ranging from 500 to 1100 meters. In order to account for the complex topography and thick vegetative cover, a surface roughness length of 2 m was used to represent the modeling area.

7 MODELING RESULTS

7. / *Annual Concentrations*

The annual average ground-level concentrations resulting from the FDM runs were plotted as isopleths. The isopleths for PM$_m$ and TSP concentrations are presented in Figures 4 and 5, respectively.

The maximum annual average ground-level PM|„ concentration due to mine operations was estimated as 12.7 pg/nr^1. This maximum concentration was located immediately southeast of the waste rock stockpile (Fig.4). The influence of the PM|,i emissions from the mine was very limited in terms of area coverage. The majority of the PM$_m$ impacts occurred within the mine property. The concentration increase within the direct area of influence due to proposed mine operations was less than 5 lig/m^1. The increase in the indirect area of influence (and the town of Miramar) was less than I |ig/nr\ All the estimated PM m concentrations are much lower than the Costa Rican (85 pg/nr^1) and World Bank (50 pg/nr^1) annual standards (Table 3).

The maximum annual average ground-level TSP concentration due to mine operations was estimated as 22.2 pg/nr^1. The maximum TSP concentration was in the same location as the maximum PM|(I concentration. The concentration increase due to proposed mine operations within the direct area of influence was less than 10 pg/nr and within the indirect area of influence was less than I pg/nr^1. All the estimated TSP concentrations are much lower than the Costa Rican (150 Hg/m^3) and World Bank (80 pg/nr^1) annual standards (Table 3).

7.2 *Daily Concentrations*

The predicted daily ground-level concentrations within one year were ranked according to their numerical values without giving consideration to the date and location. The top-50 concentrations from this ranking are presented in Figure 6. The highest predicted daily concentrations were 76.4 pg/nr and 44.7 pg/nr^1 for TSP and PM,,,, respectively. The locations of these maximum daily concentrations coincided with the location of the maximum annual concentrations. Both the predicted daily TSP and PMio concentrations are well below the World Bank standards.

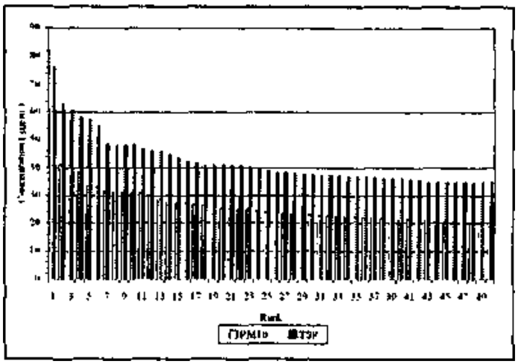

Figure 6: Daily Top-50 TSP and PM,,, Concentrations.

8 CONCLUSIONS

Based on the predicted particulate matter eoncentrationa, it can be concluded that most of the impacts will be within the mine site area. These impacts will not be very significant and will meet the Costa Rican and the World Bank ambient air quality standards. The fugitive dust impact to the direct area of influence and the indirect area of influence will be insignificant. The annual incremental PMio and TSP concentrations due to mine operations will be less than 1 pg/m'^{1} in the town of Miramar and the northeastern forest area.

REFERENCES

Environment Australia. 1998. *Diixt Control - Booklet in a Serins on Best Practice Environmental Management in Minini-*. June 1998.

Herrera. W.S., 1998. *Climatic Study of lite Bellavista Mine unci Its Surroundings,* San .lose. Cota Rica. December, 1998.

ISO. 1995. *Air Quality - Particle Size Fraction Definitions for Health Related Sampling.* ISO No. 7708, April 1995.

Setimel G.A. and W.H. Hodgson. 1978. *Model for Predicting Dry Deposition of Particles and Gases to Environmental Surfaces.* PNL-SA-6721. Batelle Pacific Northwest Laboratories. Richland. WA.

USEPA. 1992. *User's Guide for the Fugitive Dust Model (FDM) - Volume I - User Instructions.* Seattle, WA.

USEPA. 1995a. *Compilation oj Air Pollutant Emission Factors.* AP-42. Fifth Edition. Office of Air Quality Planning and Standards. Emissions, Monitoring and Analysis Division. Research Triangle Park, NC.

USEPA. 1995b. *Users Guide for the Industrial Source Complex (ISC3) Dispersion Models - Volume II - Description of Model Algorithm.* Office of Air Quality Planning and Standards. Emissions, Monitoring, and Analysis Division. Research Triangle Park, NC.

USEPA, 1996. *Meteorological Processor for Regulatory Models (MPRM) User's Manual.* Office of Air Quality and Planning and Standards. Research Triangle Park, NC 2771 I.August, 1996.

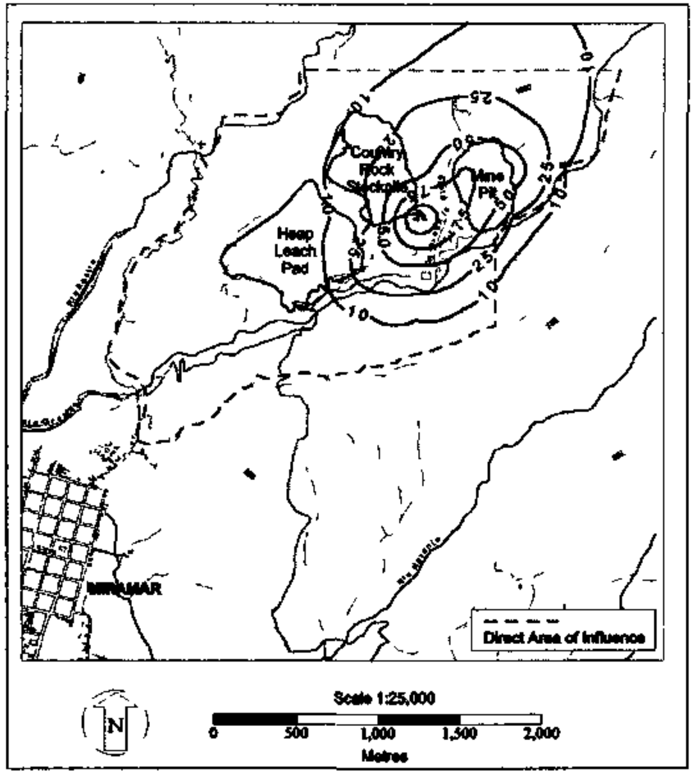

Figure 4 Estimated Annual Average PM_{10} Concentrations (µg/m^3)

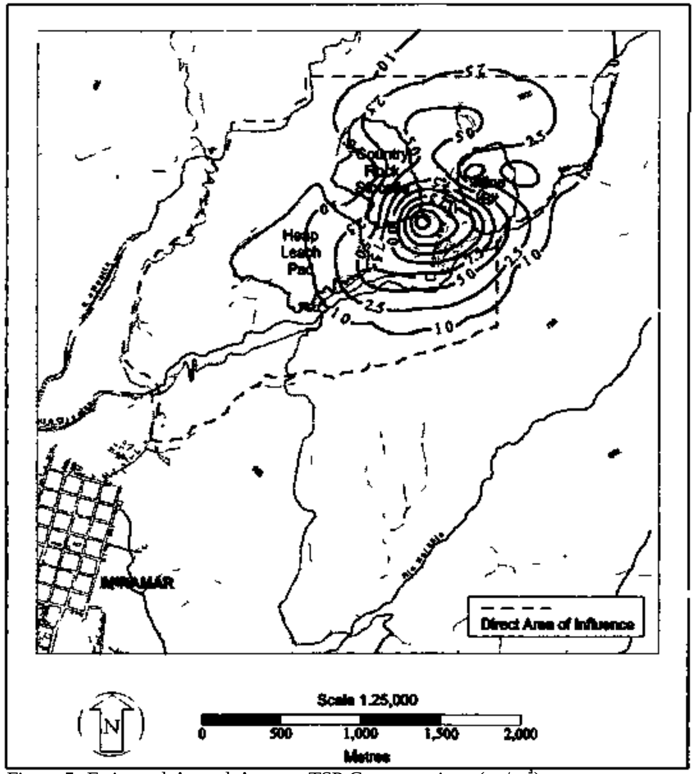

Figure 5 Estimated Annual Average TSP Concentrations (µg/m^3)