COMPUTER MODELING OF INDUSTRIAL EMISSIONS

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This thesis was submitted to the Department of Civil Engineering

Of the University of Moratuwa in partial fulfillment of the requirements

for the degree of

Master of Science

In Environmental Engineering and Management

Department of Civil Engineering
University of Moratuwa
Sri Lanka

November 2006

The work included in this dissertation in whole or part has not been submitted for any other academic qualification at any institution.

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Abstract

Air being an important part of the environment is always required to be in a satisfactory condition for the proper functioning of the entire eco system. Air quality is being affected adversely due to several reasons such as increasing number of industries without having proper emission handling systems and increasing number of vehicles.

Many industrial stacks observed in Sri Lanka today are not constructed according to the proper stack design requirements. The quality of stack emissions or the dispersion of pollutants from a specific stack is seldom analyzed mainly because of the high costs involved. Even analysis is done on the dispersion from a specific stack it is difficult to get good representative results because the meteorological conditions vary frequently.

In this study a stack emission dispersion model named AUSPLUME which is developed by the Victorian Environmental Protection Authority and recommended by several organizations for regulatory purpose was studied. This work mainly looks at the following:

i. The applicability of the model in the Environmental Impact Assessment (EIA)

ii. Model emissions from the stacks at Holcim Lanka cement plant at Puttlam with the use of AUSPLUME before and after installing a new dust handling system

The purpose of the EIA is to predict and identify potentially significant environmental impacts of development projects and to suggest mitigation measures to minimize the negative impacts and maximize the positive impacts. Main stages in the EIA process are,

i. Screening (find out whether an EIA is required)

ii. Scoping (identification of main issues)

iii. Collection and analysis of information

iv. Public involvement

v. Communicating the findings

In the process of analyzing the information AUSPLUME can be used. With available information about the stack, emissions and the meteorological data of the area of concern, the model can predict the concentrations of selected constituents at ground level or elevated levels in the down wind direction. The areas of worst impact, limit of the buffer zone, effects to the high rise buildings or effects to the selected areas of important like high bio diversity, archeology, and residences can be identified using the results obtained with AUSPLUME.

For the analysis of the stack emission dispersion from the Holcim Lanka cement plant at Puttlam, the meteorological data obtained at the Palavi weather monitoring station of the Meteorological Department were used. There are two similar stacks at the factory which are placed close by and therefore both of them were considered as a single point source with an equivalent diameter. The area was considered to be a flat terrain since there were no disturbances in the vicinity.

The analysis results on the dispersion of particulate matter, NO_2 and SO_2 emissions from the stack were compared with ambient air quantity standards for Sri Lanka and European Guideline values which were established by considering human health hazards other than carcinogenity. Certain values were found to be above the limits and the rest below the limit. Anyway in this analysis raw emission data were used and in the real life the raw emissions are mixed with clean air before released to the atmosphere. Therefore due to the dilution the real values can be expected to be much lower.

Predicted values were compared with field measurement values available and with predicted values from SCREEN3 model.

The results obtained can be used for decision making purposes with a good understanding about their inaccuracy.

Acknowledgement

I acknowledge with gratitude General Management of Ecolcim, Mr George Nicole, in giving me the opportunity to carry out this study focusing the operations in the Holcim Lanka cement plant at Puttlam.

I am grateful to Prof. Ajith De Alwis and Dr Manisha Y. Gunasekara my co supervisors whom very generously spared their precious time and provided every guidance and assistance to carry out this task.

I am also thankful to Mr Chalaka Fernando- Environmental Manager, Ms Vijitha Jayawardena- Electrical Engineer and the other staff members at the Puttlam cement plant for providing their kind assistance and sparing their precious time.

I extend my gratitude to Prof. Arjuna De Soyza and Mr Shantha Fernando at the Department of Mathematics and Philosophy of Engineering, Open University, Nawala for giving me the opportunity to continue this study.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

ADOM	Acid deposition oxidant model
CIT	California institute of technology
DWM	Diagnostic wind model
EIA	Environmental impact assessment
ID	Identity
ISC	Industrial Source Complex
ISCLT	Industrial Source Complex Long Term
ISCST	Industrial Source Complex Short Term
ppm	Particles per million
PM10	Particulate matter less the 10 μm in diameter
POP	Persistent Organic Pollutants
RADM	Regional acid deposition model
ROM	Regional oxidant model
SPM	Suspended particulate matter
SAARC	South Asian Association for Regional Corporation
UAM	Urban airshed model
USEPA	United States environmental protection agency

List of Notations

Al	Aluminum
Ca	Calcium
$CaCO_3$	Limestone
CO_2	carbon dioxide
C(x,y,z)	the downwind concentration at a point x,y,z , $\mu g/m^3$
d_s	diameter of the stack
Fe	Iron
Fe_2O_3	Iron Ore/Mill Scale
H	the effective stack height, m
h_s	physical stack height
NO_2	nitrogen dioxide
P	wind profile exponent, varies with the type of ambient weather conditions; ranges from 0.1 for calm conditions to 0.4 for turbulent weather conditions
Q	emission rate of the pollutants, g/s
Si	Silicon
SiO_2	Sand
SiO_2, Al_2O_3, Fe_2O_3	Shale, Clay
SO_2	sulphur dioxide
u	the mean vertical wind speed across the plume height, m/s
u_s	wind speed at stack height (m/s)
U_1, Z_1	wind speed, vertical height of the wind station
U_2, Z_2	wind speed, height of the plume
v_s	emission velocity (m/s)
$\bar{x}$	mean
y	the lateral distance, m
z	the vertical distance, m
ΔH	plume rise
σ	standard deviation
σ_y, σ_z	plume standard deviations, m

CHAPTER 1 : INTRODUCTION

1.1 Current air quality scenario in the country

Air is a vital ingredient to the survival of life on earth. The composition of atmosphere is very much important too. The changes in the composition of air can cause harmful effects to the life on earth. This scenario of presence of undesirable material in air, in quantities large enough to produce harmful effects is known as the air pollution (Nevers, 1995). Of all the different types of pollution affecting the life on earth air pollution is the most important. The air polluted at a certain place can travel to another place quickly and create a problem, which is never expected.

Air pollution has become a main concern since the industrial revolution. Most of the undesirable emissions to the atmosphere are related to anthropogenic industrial activities. Power generation, fuel combustion, petroleum refining, fossil fuel burning, vehicular emissions, chemical operations can be considered as the main causes of air pollution, which can result in harmful effects today or in future.

Several initiatives have been taken by many countries to reduce air pollution. For example Clean Air Act- UK (1956), USA (1970) and Carbon Credits can be mentioned.

When Sri Lanka is considered, we have not faced air pollution of serious magnitude and the air pollution is not among five key environmental issues of the country (Ministry of environment and natural resources, 2000). This may be because of the location of the country. Sri Lanka is an island in the Indian Ocean. It has continuous sea breeze, monsoon and inter monsoon winds which keep the air always in motion.

Recent observations have shown that the air shed out in the cities contains lot of unnecessary matter. According to the observations 80% of the urban air pollution is due to the transport sector. About 1.5 million vehicles are present in the country and a significant majority is in the Colombo city. The government of Sri Lanka has imposed standards on fuels and vehicle emissions.

Continuous ambient air quality monitoring is being carried out in two locations in Colombo since 1996. One location is at Colombo Fort Railway Station and the other at the Colombo Meteorological Department. According to the observations for the period of 31/12/2000 to 06/01/2001 the maximum recorded SO_2 concentration was 0.107 ppm. It is very important to monitor the air quality continuously to identify the variation of concentration for better decision making.

It is clear (Table 1.1) that the transport sector and the power sector contribute to the majority of air pollution due to CO_2 emissions and a higher emission rate is expected with the trend for increased reliance on coal and oil based thermal power generation in future.

A sectoral comparison is given in Table 1.1 (SAARC, 2002).

Table1.1: CO_2 emission under baseline scenario through energy generation

Year / Sector	1990	1995	2000	2005 (predicted)
Energy from fossil fuels (Gg)	**3306.18**	**5181.39**	**7017.97**	**12528.82**
Power	8.51	615.78	1904.09	6445.06
Transport	2213.42	3188.72	3481.51	4067.40
Domestic	550.49	727.48	896.29	1055.11
Industry	533.76	649.41	790.08	961.25

Industrial sector has potential for air pollution and at present accounting for nearly 93% of the SO_2 emissions (SAARC, 2002).

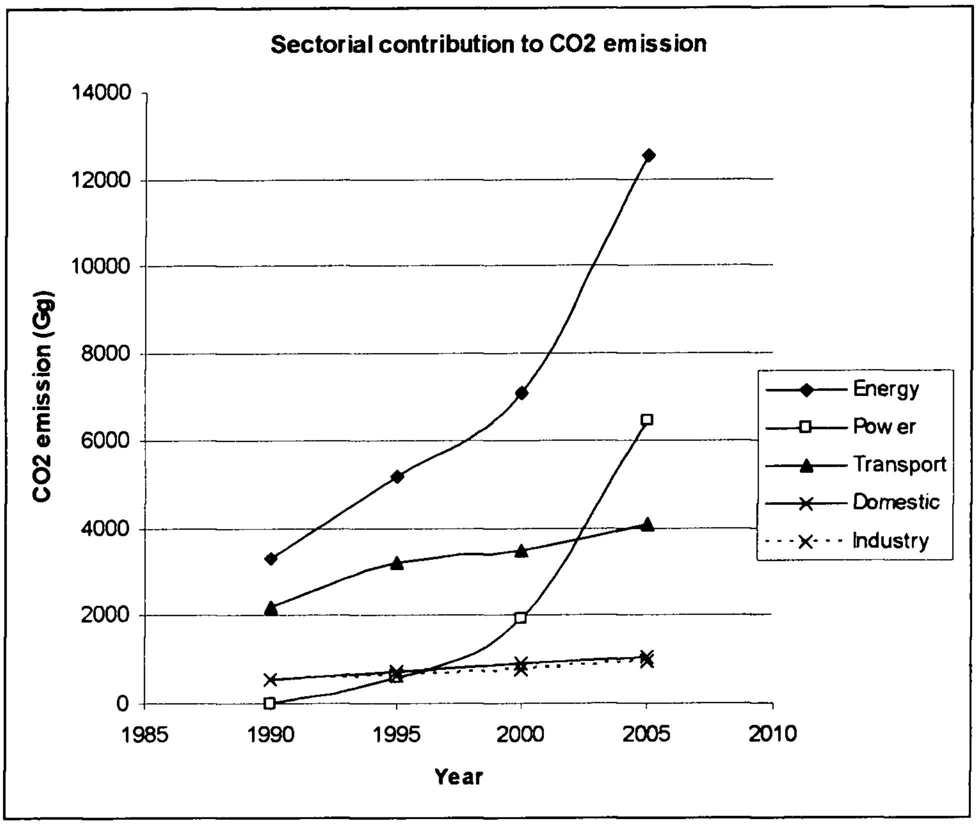


Figure 1.1: CO_2 emission under baseline scenario through energy generation

The 2002 SAARC report highlights a specific example where of an industrial activity can create air pollution. It describes air pollution being 'very high from Puttlam Cement, which gives out several tons of particulate matter into the atmosphere, causing considerable health problems and loss of agricultural productivity of the area'. Since 2002, however, the company has done several improvements and demonstrated commitment to reducing the emissions and improving its environmental performance. An in depth analysis of the level of improvement with regards to certain emission parameters is provided in chapter 4.

1.1.1 How to handle the air pollution

The mitigation of air pollution effects can be done by reducing the emissions that contribute to the pollution. The pollution can be a result of industrial processes, accidental, intentional or incidental releases like explosions in war, volcanoes, lightning, vegetative and soil emissions.

When systematic and rational strategies are necessary for responding or mitigating the releases the following must be known.

- The rates and locations of emissions to establish a baseline from which changes are intended
- The chemical and physical reactions transforming emissions to gaseous, aerosol, and dissolve products
- Locations where emitted and transformed materials will be dispersed by atmospheric motions (wind)
- Rates of removal by deposition
- Downwind exposures
- Health, environmental, and economic consequences of exposure
- Available technologies for reducing emissions and their costs
- The process by which exposures will respond to emissions changes

It is also necessary to identify reasonable alternative strategies for mitigating impacts and ways to distinguish those that are most likely from those less likely to meet the objectives, be they health- and welfare- related or economic.

Due to the chemical and physical complexity involved in industrial emissions, it is numerical models that can be employed successfully for simulating almost all the atmospheric phenomena of interest. Models are used for exploring how pollutant concentrations will change when emissions are changed into the atmosphere.

1.2 Research objectives

Air being an important part of the environment is always required to be in a satisfactory condition for proper functioning of the entire eco system. Air quality is affected due to several reasons such as increasing number of industries and vehicles. Current practice is to carry out an Environmental Impact Assessment (EIA) before a new industry is started. The purpose of the EIA is to predict and identify potentially significant environmental impacts of development proposals and to suggest mitigation measures to minimize the negative impacts and maximize the positive impacts. Monitoring emissions from industrial activities during plant operation helps identification and prevention of adverse environmental impacts.

In the EIA process estimating the distribution of emitted substances from a stack into the environment can be done using a model. For this purpose identifying mathematical models to use in EIA studies in Sri Lanka as well as in modeling emissions from existing plants is needed. Several models have been used for EIA (Annexure 2) in Sri Lanka. But it is better if there is a specific model recommended for all EIAs.

In the case of existing industries the regular measuring of the stack emission dispersion needs lot of money. Dispersion models can be used for predicting the dispersions and field measurements can be done for the validation from time to time.

The objectives of this research project are,

- Predicting the downwind concentrations of a substance in the stack emission to find out its applicability for EIA
- Analyzing the emission dispersion from stacks at Holcim Lanka Puttlam factory before and after installing a new dust handling system.

CHAPTER 2: LITRATURE REVIEW

2.1 Air quality modeling

A modeling system can be described as a systematic integrator of knowledge about the response of the atmosphere to natural and artificial perturbations, such as weather, changes in land use, and emissions, and the social and economic ramifications of those perturbations.

For continuous modeling applications it is required to have regular emission inventories, which require information on emission factors, activity levels required, temporal and spatial variations in biogenic as well as anthropogenic emissions on scales comparable to those in the models and in a format that can be assimilated by them.

Meteorological data like temperature, wind velocity are needed to estimate biogenic and compound emissions, and to use in chemistry, transport diffusion and deposition algorithms. Meteorological models can be used in the estimation of the above parameters which can assess and format input data, either historical or real time and produce the input to the air quality or emission models.

For regional and urban scale air quality models, in addition to meteorological and emissions data, input information such as air quality data for initialization and for boundary conditions are also required. These models also need land use information for analyzing the depositions.

2.1.1 Model types

A model is something that simulates one of the many aspects of the air quality assessment system. The aspects which can be simulated in a model are emissions, meteorology, air quality, and decision analysis or risk management. Less complex modeling systems treat fewer aspects with less detail. Comprehensive modeling systems are able to treat all aspects at whatever level of detail that can be formulated and afforded. A schematic representation of the relationships among the major components of an air quality modeling system is given below in Figure 2.1 (Hansen)

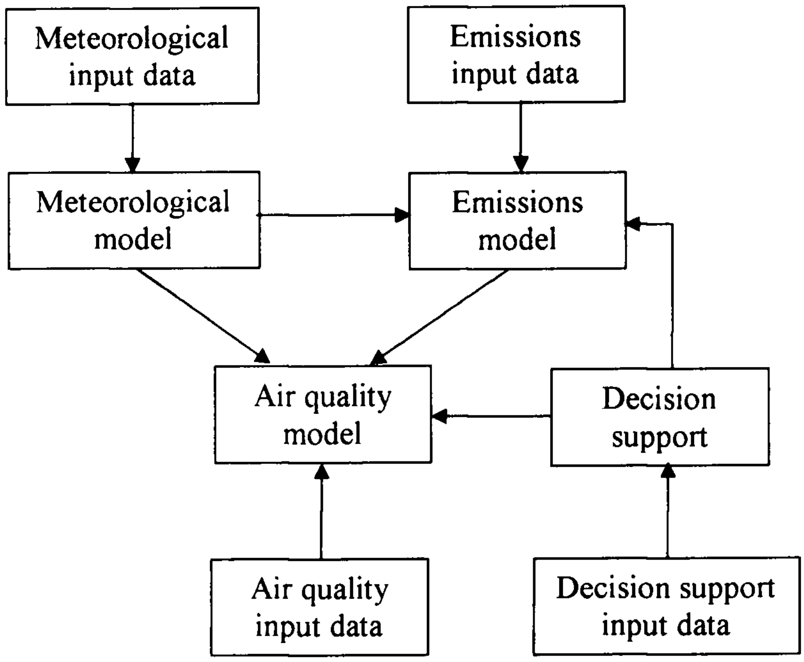


Figure 2.1: Relationships among the major components of an air quality modeling system

2.1.2 Emissions

Emissions are categorized as biogenic, geogenic and anthropogenic. Biogenic emissions come from terrestrial and aquatic organisms as they live and die. Geogenic emissions are primarily volcanic, fossil organic depositions, gases formed during lighting discharges. Anthropogenic emissions are emissions due to man's activities and are generally classified as point sources (medium to large stacks), area sources (fugitive emissions and small dispersed sources) and mobile sources (vehicles). Within each of these types there are dozens of specific source types. Many sources vary with time because of activity schedules and meteorological conditions.

A model must be able to assimilate information on future conditions for example with implementation of selected control techniques, with demographic changes or for different climates and project what emissions will be under those conditions. It also must be capable of estimating error bounds on the emissions estimates so that the uncertainty of the estimates can be taken into account in doing air quality modeling.

2.1.3 Meteorological

Meteorological models are used to simulate the physical state of the atmosphere, wind velocities, water vapor mixing ratios, cloud cover and precipitation. This information is necessary to input in emissions, dispersion and air quality models.

There are two types of meteorological models.

1. Diagnostic

   These models mainly rely on observational data as the basis for interpolation and extrapolation to the models grid domain. They cannot predict future states of the atmosphere but merely estimate the state corresponding to the input data.

2. Prognostic

   These models have the ability to forecast future states of the atmosphere. This is done by applying the knowledge of atmospheric physics for simulating the atmospheric conditions. This is useful when there are no observations and for forecasting future conditions.

2.1.4 Air Quality Models

Air quality models use numerical methods to form the bridge between the fields simulated by emissions and meteorological models and the concentrations and depositions of the air constituents of interest. They can be formulated in one, two or three dimensions. There is also the zero dimensional model, which may accept temporary variable but spatially invariant meteorological input. All of them simulate the temporal development of the relevant chemistry and physics.

Zero dimensional model is a box model. The size of the box is arbitrary and does not need to be specified. Materials preexisting in the box and introduced and lost from it are represented in concentrations, mixing ratios or masses per unit volume. Transport and diffusion are not allowable concepts in zero dimensions. A box model can be envisioned as a simulated well mixed smog chamber.

One dimensional model also performs their accounting in terms of concentrations. Unlike the box model, however they allow concentration and pressure gradients to exist and move along their one dimension by diffusion or advection or convection. They are generally oriented to simulate vertical profiles and are useful when simulating gross average properties in the horizontal unsimulated dimension.

Two and three dimensional models are of three types generally.

I. **Gaussian,** is essentially one dimensional along the axis of movement and one or two dimensional, with a Gaussian concentration distribution, along the axis (es) perpendicular to the axis of movement.

II. **Lagrangian,** where the frame of reference moves with the simulated motion of the air. This type includes puff models, Lagrangian particle models and box trajectory models.

III. **Eulerian,** the frame of reference is fixed and gridded. Air moves across grid cell boundaries either by diffusion or by advection according to the mass continuity equation. These models are often referred as grid models too. They are the most complex models in use. The more advance once need inputs such as four dimensional fields of wind velocity, temperature, water vapor mixing ratio, clouds, solar and reflection radiation and precipitation, three dimensional gridded topography and two dimensional land use data, four dimensional spatiated emission strengths.

2.2 Examples of air quality modeling systems

The air quality modeling systems described below are widely used in the world (Hansen).

2.2.1 Urban Airshed Model, Version IV (UAM- IV)

This is the most widely used urban scale photochemical grid model in the world today. A photochemical grid model is an Eularian air quality model that does not include wet deposition or aerosol dynamics. The only chemistry simulated is in the gas phase. This model has been applied and evaluated in over 34 cities, 26 in United States and 8 abroad, including Athens, Turin, Thaipei, Kaohsiung, Tokyo, Mexico City and Malbourne. It has been applied in areas with meteorological conditions that range from simple to complex, coastal and inland locations, mild to severe ozone problems, emissions configurations ranging from low to high spatial variability, and data bases that range from sparse to rich.

The UAM- IV modeling system includes following components.

- 3- D Photochemical grid model for estimating ozone and precursor concentrations
- The Diagnostic Wind Model for generating physically realistic 3- D wind fields
- Emissions Processing System Version 2.0 which generates hourly, gridded, speciated emissions data required by a photochemical grid model
- The U.S. EPA's Regional Oxidant Model(ROM)/ UAM interface system for generating initial concentrations and boundary conditions inputs from outputs from ROM
- Assorted additional preprocessing programs for generating additional inputs

2.2.2 Urban Airshed Model, Version V (UAM- V)

There are currently two models centered on the UAM- V; the Lake Michigan Ozone Study (LMOS) Photochemical Modeling System and the UAM- V modeling system. These systems have been used in Lake Michigan, Gulf of Mexico, Atlanta, Northeast United States and the other regions.

The numerical basis of this model is atmospheric diffusion or species continuity equation. This equation represents a mass balance, in which all of the relevant emissions transport, diffusion, chemical reactions, and removal processes are expressed in mathematical terms. The model is typically applied to a 48 to 120 hr period during which meteorological conditions contribute to elevated concentrations of the chemical species of interest, usually ozone. In this model species continuity equation is solved using the method of fractional steps in which the atmospheric diffusion equation is solved separately in the following order.

i. Emissions are injected
ii. Horizontal advection/ diffusion is solved
iii. Vertical advection/ diffusion and deposition is solved
iv. Chemical transformations are performed for reactive pollutants

UAM- V has some additional features over the UAM- IV, which are given below

i. The vertical layer structure can be arbitrarily defined by the user and is no longer defined from the diffusion break (mixing height). This allows for higher resolution vertical layers near the surface and better matching with output from prognostic meteorological models.
ii. Several meteorological variables that were considered spatially constant now vary temporally and spatially (temperature, moisture, pressure, photolysis rates). Horizontal diffusion and vertical turbulent exchange coefficients are required which are calculated from prognostic meteorological models.

iii. A chemical aggregation scheme has been implemented. The chemistry calculations can be performed on a variable grid while the advection/ diffusion and emissions injections are performed on a fixed grid.
iv. Aqueous phase chemistry has been added.
v. The dry deposition algorithm has been implemented.
vi. Advanced prognostic meteorological models have been developed to support the application of this model to regional or urban domains.
vii. Concentrations are advected and diffused in the model using units of mass per unit of volume rather than ppm to maintain a true mass balance during the advection and diffusion.

2.2.3 CIT/ CMU/ MIT/ Urban- Regional Multigrid Model Series

This model was originally developed as a gas phase photo chemical air quality model by the California Institute of Technology and later the ability to track the formation and transport of aerosol nitrate was added. This has been mainly used as a research tool.

The CIT model includes terrain-following coordinate system, operator splitting, which allows specialized techniques to treat individual components of the atmospheric diffusion equation, combined vertical and chemical operators, and an implicit, hybrid, asymptotic, exponential chemical solver.

2.2.4 Regional Acid Deposition Model (RADM)

This is a regional Eulerian model to simulate acid deposition to receptors in America. RADM, until 1990, was a fixed grid model with horizontal grid spacing of 80 km. It had user specifiable vertical structure, but normally used with 6 or 15 unevenly spaced vertical levels, based on pressure coordinates 100 millibars.

It simulates gas- phase and aqueous- phase (in cloud) chemistry as well as wet and dry deposition. It simulates the formation of sulfate aerosol particles from both gas phase and aqueous phase oxidation of SO_2. All nitrates formed from the oxidation of NO_x is assumed to be HNO_3.

2.2.5 Acid Deposition Oxidant Model (ADOM)

This was developed in Germany and has many of the same characteristics with some important differences. Most notable differences are chemical mechanism used and the treatment of cloud processes, including aqueous phase chemistry.

ADOM has been applied in North America and Europe, looking at both acid deposition as well as ozone control.

2.2.6 MEMO/ MARS (EUMAC Zooming model)

This model includes a nonhydrostatic meteorological model (MEMO) that is linked to a photochemical (MARS) model.

MEMO is a prognostic, nonhydrostatic model that solves the conservation of mass, momentum, and scalar quantities (potential temperature, kinetic energy and humidity). It includes and inelastic approximation to filter sound waves. Varying grid spacing can be used in each direction. Turbulent diffusion is followed using a one- equation model.

MARS is a 3- D photochemical model. It treats vertical diffusion and chemistry together.

This model has been applied in a variety of domains, including Athens, Thessaloniki, Barcelona and Lisbon.

2.2.7 RAINS ASIA Model

The Regional Air Pollution Information and Simulation (RAINS-ASIA) model is a tool to analyze cost-effective strategies for reducing environmental impacts of SO_2 emissions in Asia. The first version of the model was developed in result of the RAINS ASIA Phase 1 Project. The results of that phase are documented in the report by Foell et al., 1995. In the phase 2 of the project the model was further extended and updated. The main features of RAINS ASIA 2 model include:

- Estimates of present and future (1990-2030) sulfur emissions in Asia for the baseline economic development scenarios
- More than 100 administrative regions and 400 individual large point sources
- Assessment of the effectiveness of emission control measures
- Cost estimates of emission control strategies
- Assessment of the atmospheric dispersion of SO_2 emissions
- Impacts of emission control measures on regional sulfur deposition and SO_2 concentrations levels
- Optimization tool to identify least-cost emission control measures
- On-line help system.

The various sub-models are organized into three modules:

- The energy-emissions module (EMCO)
- The deposition and critical loads assessment module (DEP)
- The optimization module (OPT)

Flow of information in this model is given below.

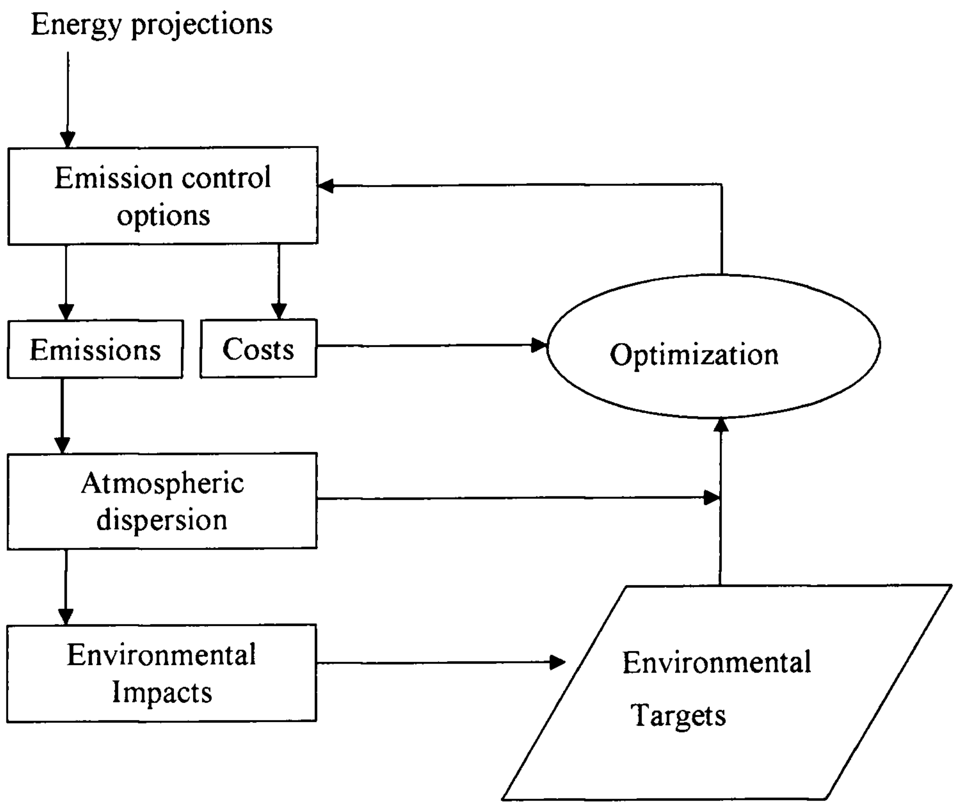


Figure 2.2: Flow of information in RAINS ASIA 2

2.2.8 AERMOD

AERMOD is a 'near-field, steady-state' guideline model. It uses boundary-layer similarity theory to define turbulence and dispersion coefficients as a continuum, rather than as a discrete set of stability classes. Variation of turbulence with height allows a better treatment of dispersion from different release heights. Also, dispersion coefficients for unstable conditions are non-Gaussian, to represent the high concentrations that can be observed close to a stack under convective conditions.

AERMOD was developed in 1995, reviewed in 1998 and formally proposed by the US EPA as a replacement for ISCST3 in 2000. However, this status has not yet been achieved and is likely to take some time.

2.2.9 SCREEN 3 Model

The SCREEN 3 model has been developed to provide an easy method to predict pollutant concentrations mainly for screening purposes (USEPA, 1995). SCREEN 3 can perform single source, short-term calculations, including estimating maximum ground-level concentrations and the distance to the maximum, incorporating the effects of building downwash on the maximum concentrations for both the near wake and far wake regions, estimating concentrations in the cavity recirculation zone, estimating concentrations due to inversion break-up and shoreline fumigation, and determining plume rise for flare releases.

The model examines a full range of meteorological conditions, including all stability classes and wind speeds to find maximum impacts.

2.2.10 AUSPLUME Model

Ausplume is a Gaussian plume dispersion model whose mathematical basis derives from the Victorian Environment Protection Authority's "Plume Calculation Procedure" (EPAV 1985), which is an extension of the ISC model of Bowers et al. (1979). It is designed to predict ground-level concentrations or dry deposition of pollutants emitted from one or more sources, which may be stacks, area sources, volume sources, or any combination of these. Line source are not explicitly handled, but it is possible to improvise by modelling with multiple volume sources.

Applications are in the following areas:

- stack height determination
- identification of the main contributors to existing air pollution problems
- new source assessment
- control strategy evaluation
- monitoring network design

To provide for the range of averaging times that are important for different pollutants, Ausplume can be directed to compute concentrations or deposition averaged over the following intervals:

- → any number of minutes from 3 to 60 minutes
- → 1,2, 3, 4, 6, 8, 12 or 24 hours
- → rolling hourly averages
- → 7 days
- → 90 days (as a running average computed daily)
- → months (as a running average computed monthly)
- → the full period for which meteorological data is given.

Flow of information in this model is simply given below.

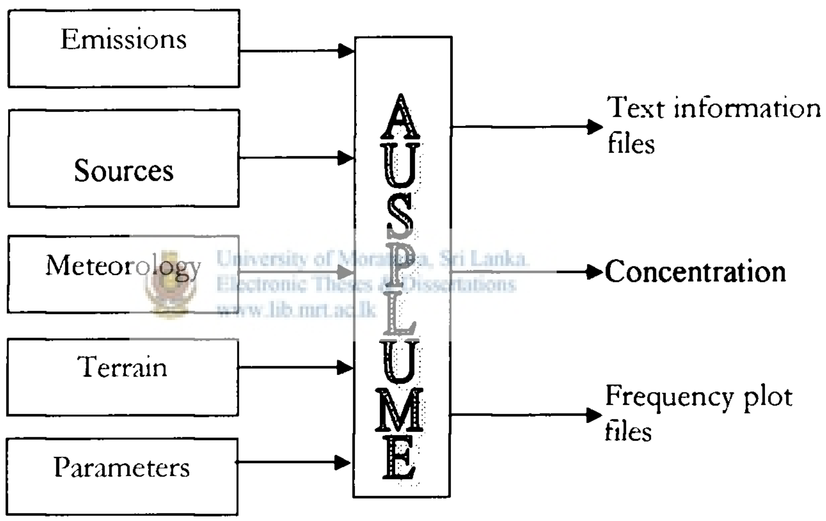


Figure 2.3: Flow of information in AUSPLUME

AUSPLUME model has been used in achieving the objectives of this study since it has been used by many countries for regulatory purposes, it has a wide variety of applications and the results can be easily interpreted.

2.3 Atmospheric dispersion modeling- The Gaussian Model

The goal of air quality dispersion modeling is to estimate the concentration of elements of concern at a point downwind of one or more of sources. The Gaussian based model is effective for representing plume diffusion for a range of atmospheric conditions. The technique applies the standard deviations of the Gaussian distribution in two directions to represent the characteristics of the plume downwind of its origin. The plumes shape and hence the standard deviation varies according to different meteorological conditions.

The following equation gives the ordinate value of the Gaussian distribution.

$$y = [1/(\sqrt{2\pi\sigma})]\{\exp[(-1/2)(x - \bar{x}/\sigma)^2]\} \qquad (2.1)$$

Where,

σ	Standard deviation
$\bar{x}$	Mean

Which is depicted as a bell shaped curved given below.

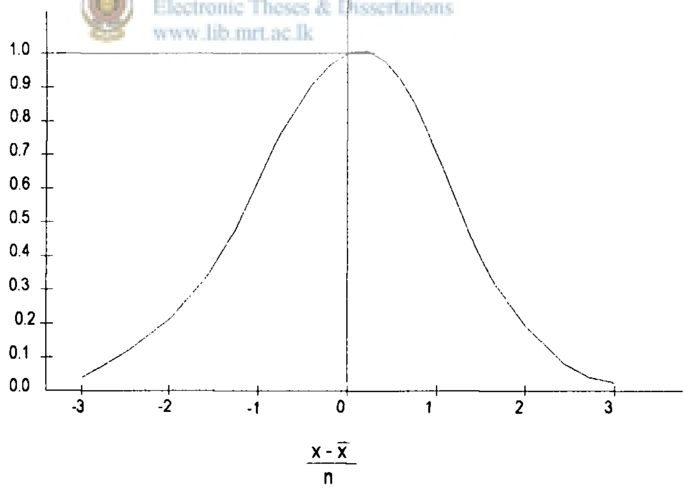


Figure 2.4: Gaussian (Normal) Distribution curve

The coordinate system used in models dealing with the Gaussian equation defines the x axis as downwind of the source, the y axis as horizontal (lateral) to the x axis and the z axis as the vertical direction. The Gaussian lateral distribution can be described as follows.(Kiely, 1997)

$$G_y = [1/(\sqrt{2\pi}\sigma_y)]\{\exp[(-1/2)(y/\sigma_y)^2]\} \qquad (2.2)$$

where,

G_y	Down wind concentration at point y
σ_y	Standard deviation in y direction

Similar Gaussian distribution can be used to describe the distribution in the z direction. The distribution of the plume around the centre line in both the y and z directions can be represented when the two single distributions in each of the coordinate directions are multiplied to give a double Gaussian distribution.

Shifting the centre line upward a distance H corrects the equation for emissions at the effective stack height (Kiely, 1997).

$$C(x,y,z) = [Q/(2\pi\sigma_y\sigma_z u)]\{\exp[(-1/2)(y/\sigma_y)^2]\}\{\exp[(-1/2)((z-H)/\sigma_z)^2 + \exp[(-1/2)((z+H)/\sigma_z)^2]\} \qquad (2.3)$$

where,

C(x,y,z)	the downwind concentration at a point x,y,z , $\mu g/m^3$
Q	emission rate of the pollutants, g/s
σ_y, σ_z	plume standard deviations, m
u	the mean vertical wind speed across the plume height, m/s
y	the lateral distance, m
z	the vertical distance, m
H	the effective stack height, m

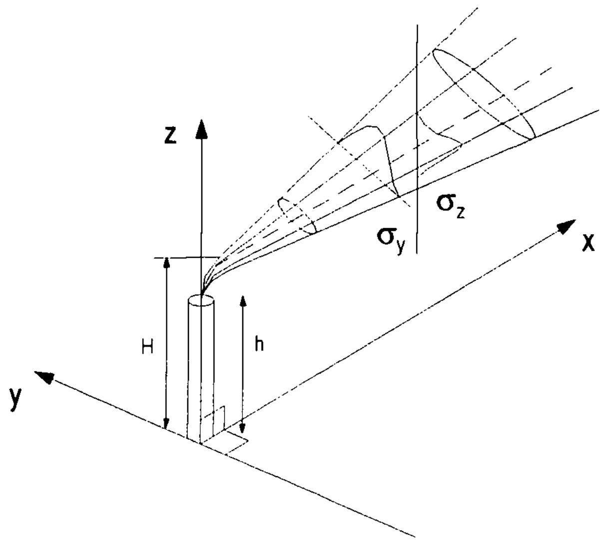


Figure 2.5: Distribution of the plume around the centre line

Assumptions typically used in Gaussian modeling are shown below. (http://www.epa.vic.gov.au).

- Steady state system (source continuously emits at a constant strength; the wind speed, direction and the diffusion characteristics of the plume remains steady and no chemical transformation takes place in the plume)
- Diffusion in the x direction is ignored although transport in this direction is accounted for by wind speed
- The plume is reflected up at the ground rather than being deposited (none of the pollutant is removed from the plume as it moved downwind)
- The model applied to an ideal aerosol or an inert gas (particles greater than 20 μm in diameter tend to settle in the atmosphere at an appreciable rate)
- The calculations are only valid for wind speeds greater than or equal to 1 m/s.

Application of the Gaussian model is limited to 50 km due to the extrapolation of the diffusion coefficients. Other factors to be influencing the model are ground condition, thermal characteristics and meteorological conditions.

2.3.1 Plume characteristics

Boilers or industrial furnaces have well defined stacks and their emissions are the most common plumes that are modeled. The hot plume emitted from the stack rises until it has expanded and cooled sufficiently to be in volumetric and thermal equilibrium with the surrounding atmosphere. The height at which the plume stabilizes is called as the effective plume height (H).

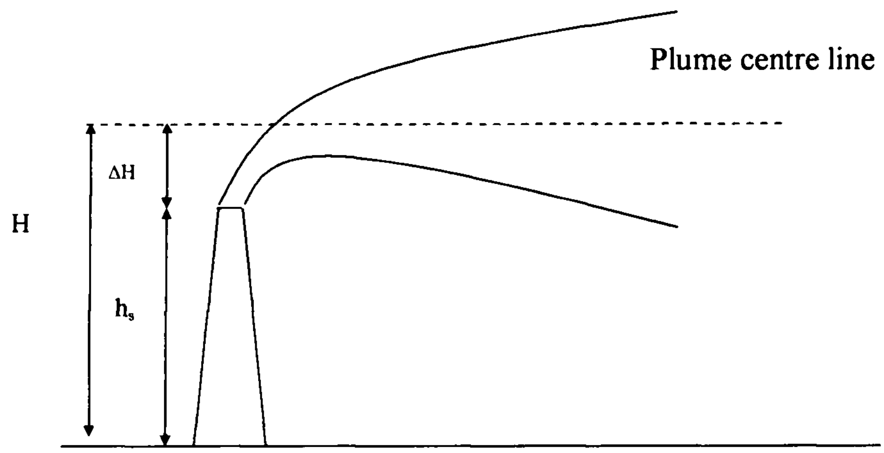


Figure 2.6: Height of a stack

$$H = \Delta H + h_s \quad (2.4)$$

Where h_s physical stack height ΔH plume rise

The plume rise is the increase in the height due to the momentum and the buoyancy effects of the plume. The momentum component is the rise due to the physical speed at which the effluent is released and the buoyancy is due to the thermal characteristic of the plume relative to the ambient air.

2.3.2 Dispersion coefficients

The σ_y and σ_z are the standard deviations of the Gaussian distribution functions. Since they describe the plume as it disperses, they increase with time and the distance traveled. σ_y is generally larger than σ_z since no stratification effects are in the y (Horizontal, perpendicular to the wind direction) direction. These are taken from Pasquill- Gifford curves (Annexure 7).

The standard deviations σ_y and σ_z characterizes the broadness or sharpness of the normal distribution of the pollutants in the plume. As σ_y and σ_z increase, the concentration value of a pollutant at the plume centre line decreases.

2.3.3 Stability classes

Atmospheric stability class is one of the conditions which have to be adjusted using Table 1.2. The atmosphere is more or less turbulent at any given time, depending on the amount of incoming solar radiation, cloud cover and surface wind speed. Meteorologists have defined six atmospheric stability classes, each representing a different degree of turbulence in the atmosphere. When moderate to strong incoming solar radiation heats air near the ground, causing it to rise and generating large eddies, the atmosphere is considered "unstable," or relatively turbulent. Unstable conditions are associated with atmospheric stability classes A and B. When solar radiation is relatively weak, air near the surface has less of a tendency to rise and less turbulence develops. In this case, the atmosphere is considered "stable," or less turbulent, the wind is weak, and the stability class would be E or F. Stability classes D and C represent conditions of more neutral stability, or moderate turbulence. Neutral conditions are associated with relatively strong wind speeds and moderate solar radiation.

Table 2.1: Stability class choices for day and nighttime (adapted from Turner 1994).

Surface wind speed at 10m(m/s)	Incoming solar radiation (during daytime)			Cloud cover (during *night time)	
	Strong	Moderate	Slight	> 5/10	< 5/10
< 2	A	A – B	B	E	F
2 – 3	A – B	B	C	E	F
3 – 5	B	B – C	C	D	E
5 – 6	C	C – D	D	D	D
> 6	C	D	D	D	D

*Nighttime is the period from 1 hour before sunset to 1 hour after sunrise.

Class D could be selected for completely overcast conditions during day or night.

Classes E and F indicate stable air in which stratification strongly dampens mechanical turbulence, typically with strong winds in a constant direction. These conditions can produce a fanning plume that does not rise much and retains a narrow shape in the vertical dimension for a long wind (Figure 2.7).

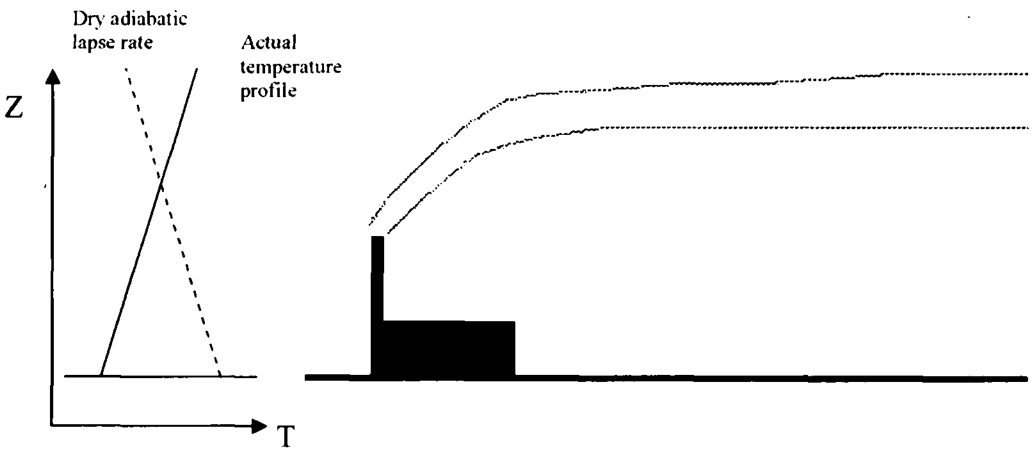


Figure 2.7: Fanning plume

The dry adiabatic lapse rate is the rate at which the temperature of a parcel of air varies with the height when there is no heat exchange between the parcel of air and the atmosphere. Under that condition,

$$dT/dZ = -0.0098$$

where,

T temperature of the parcel of air

Z height

When a plume is in a stable layer is brought quickly to the surface by turbulence in a less stable layer is called as fumigation and this can occur as a result of heat convection in the mornings.(Figure 2.8).

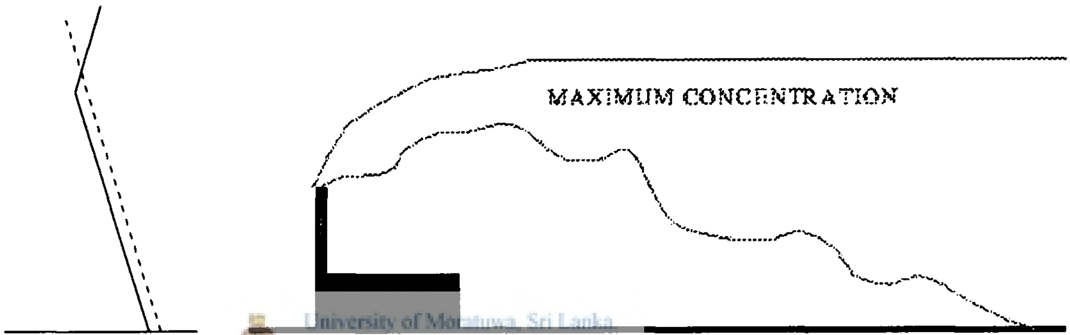


Figure 2.8: Fumigation

Class D stability is neutral, with moderate winds and mixing properties. These conditions produce a coning plume (Figure 2.9).

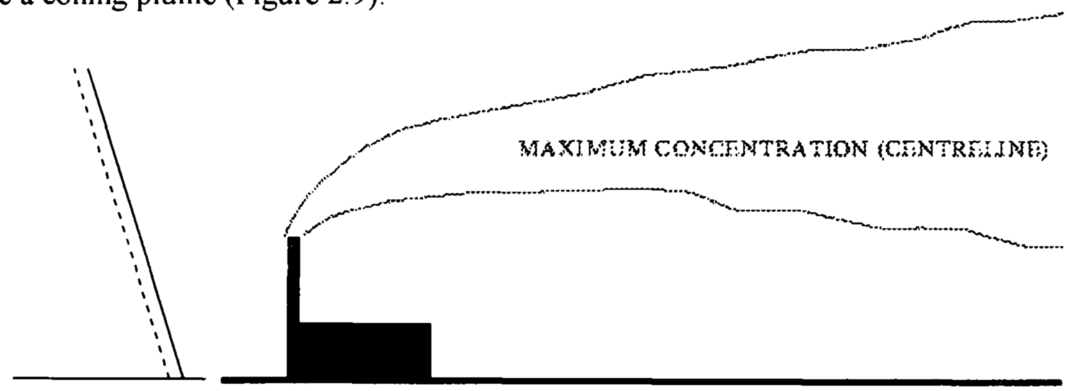


Figure 2.9: Coning Plume

Class A, B and C represent unstable conditions which indicate various levels of extensive mixing. This condition can produce a looping plume (Figure 2.10).

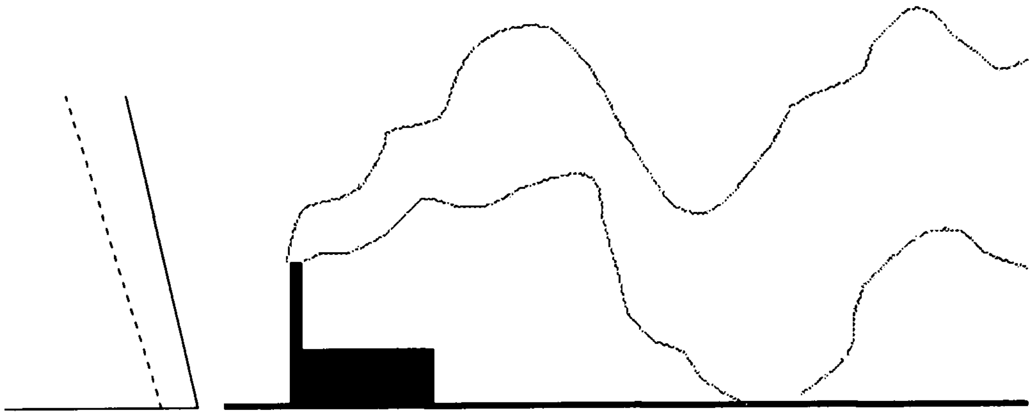


Figure 2.10: Looping

If the effective stack height exceeds the mixing height, the plume is assumed to remain above it with no ground level concentration. This effect is called lofting (Figure 2.11).

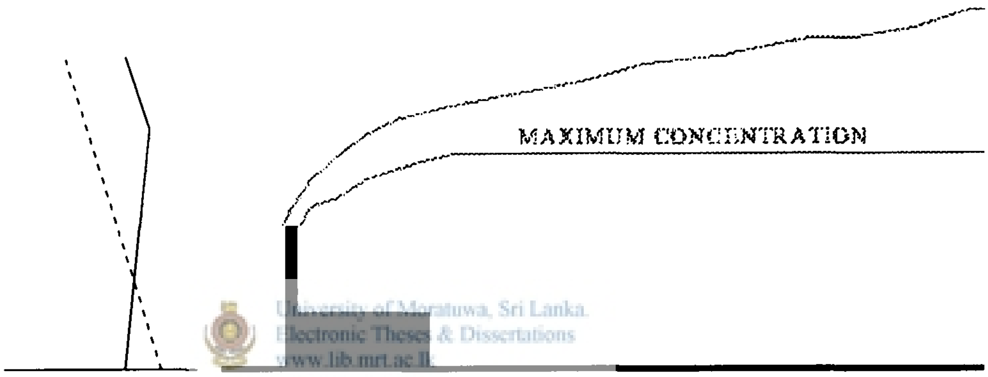


Figure 2.11: Lofting

2.3.4 Mixing height

The mixing height (the depth of the surface mixed layer) is the height of the atmosphere above the ground which is well mixed, due to either mechanical turbulence or convective turbulence. Above that height there is a stable layer.

Discharges below the mixing height generally are dispersed within the mixing layer, while discharges above the mixing height generally are dispersed above the mixing height.

Forecasting of mixing height is done with the aid of the vertical temperature profile. A radiosonde is sent aloft and temperatures at various altitudes are radioed back. The altitude at which the dry adiabatic line intersects the radiosonde measurements is taken as the Maximum Mixing Depth (MMD). The dry adiabatic line is defined as a decrease of 5.4 ^{0}F over height of 1000 feet. The MMD is a function of Stability. In Unstable air the MMD is higher and in Stable air the MMD is lower. There is a seasonal variation of mixing height. For summer daylight hours MMD can be a few thousand feet where as for winter it can be a few hundred feet. It varies also in the course of a day. It is lowest at night and increases during the day. With a measure of both MMD and wind speed with respect to height and we get a very good idea of the amount of pollutant dispersion.

Table 2.2: Typical mixing heights in km for a rural location (www.environment.nsw.gov.au)

	Wind speed (m/s)																		
Stability class	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	10	12	14	16	18	20
A	0.3	0.6	1	1.3	1.6	2													
B	0.3	0.5	0.8	1.1	1.4	1.7	1.9	2.2	2.5	2.7									
C	0.2	0.4	0.7	0.9	1.1	1.3	1.5	1.8	2	2.2	2.6	3.1	3.5	4.4					
D	0.2	0.4	0.6	0.8	1.1	1.3	1.5	1.7	1.9	2.1	2.6	2.9	3.4	4.3	5	5	5	5	5
E	5	5	5	5	5	5	5	5	5	5									
F	5	5	5	5	5	5	5												

2.3.5 Wind speed

The wind speed U, is the mean wind speed over the vertical distribution of a plume. Most of the time wind speed available is that monitored at ground level meteorological stations. These stations record ambient weather condition usually at a height of 10 m, and the wind speed measured is typically less than which affect the plume. Less value is due to the surface friction caused by the ground characteristics. Therefore wind speed power law is usually applied to convert the near surface wind speed data into wind speed representative of the conditions at the effective plume height.

The wind speed power law is,

$$U_2 = U_1 * (Z_2/Z_1)^P \qquad (2.5)$$

U_1, Z_1 wind speed, vertical height of the wind station

U_2, Z_2 wind speed, height of the plume

P wind profile exponent, varies with the type of ambient weather conditions; ranges from 0.1 for calm conditions to 0.4 for turbulent weather conditions

In dispersion modeling, the plume height is critical to the basic equation for the calculation of down wind concentration at the receptors. Several factors affect the initial dispersion of the plume and hence the plume height including, the presence of buildings or other features disturbing the wind stream flow and the physical stack height.

2.3.6 Plume rise

There are several attempts taken to estimate the plume rise but most of the equations apply to uniform or smoothly varying atmospheric conditions.

The plume rise is mainly due to two factors,

- The velocity of the exhaust gas, which imparts momentum to the plume
- Temperature of the exhaust gas, which gives the plume buoyancy in ambient air

The momentum flux comes from mechanical fans in the duct systems and the natural draft that occurs in the stack. If the gas in the plume has a density less than the ambient air, the plume will rise up adding more momentum. The momentum of the plume can be increased by constricting the exit diameter of the stack.

For most large combustion sources, the buoyancy flux dominates the momentum flux. Buoyant plumes contribute to both the vertical and horizontal velocity of the plume, in addition to that caused by ambient turbulent levels. This condition is caused by the entrainment of the surrounding air into the expanding plume in relation to its surrounding.

As mentioned earlier several factors affect the plume rise including the meteorological parameters. As these conditions vary the rise of the plume is enhanced or reduced. The final effective plume height is reached only at some point downwind of the stack. This condition is known as gradual plume rise.

2.3.7 Downwash

All large structures distort the atmosphere and interfere with wind flow to some extent. These atmospheric distortions usually take the form of a wake, which consists of a pocket of slower, more turbulent air. If a plume is emitted near a wake, it is usually pulled down because of the lower pressure in the wake region. This effect is termed as downwash. When the downwash takes place the plume is brought down to the ground near the emission source more quickly.

A wake that results in downwash may occur as a result of following conditions.

- The stack itself, stack tip downwash
- Local topography
- Nearby large structures, building downwash

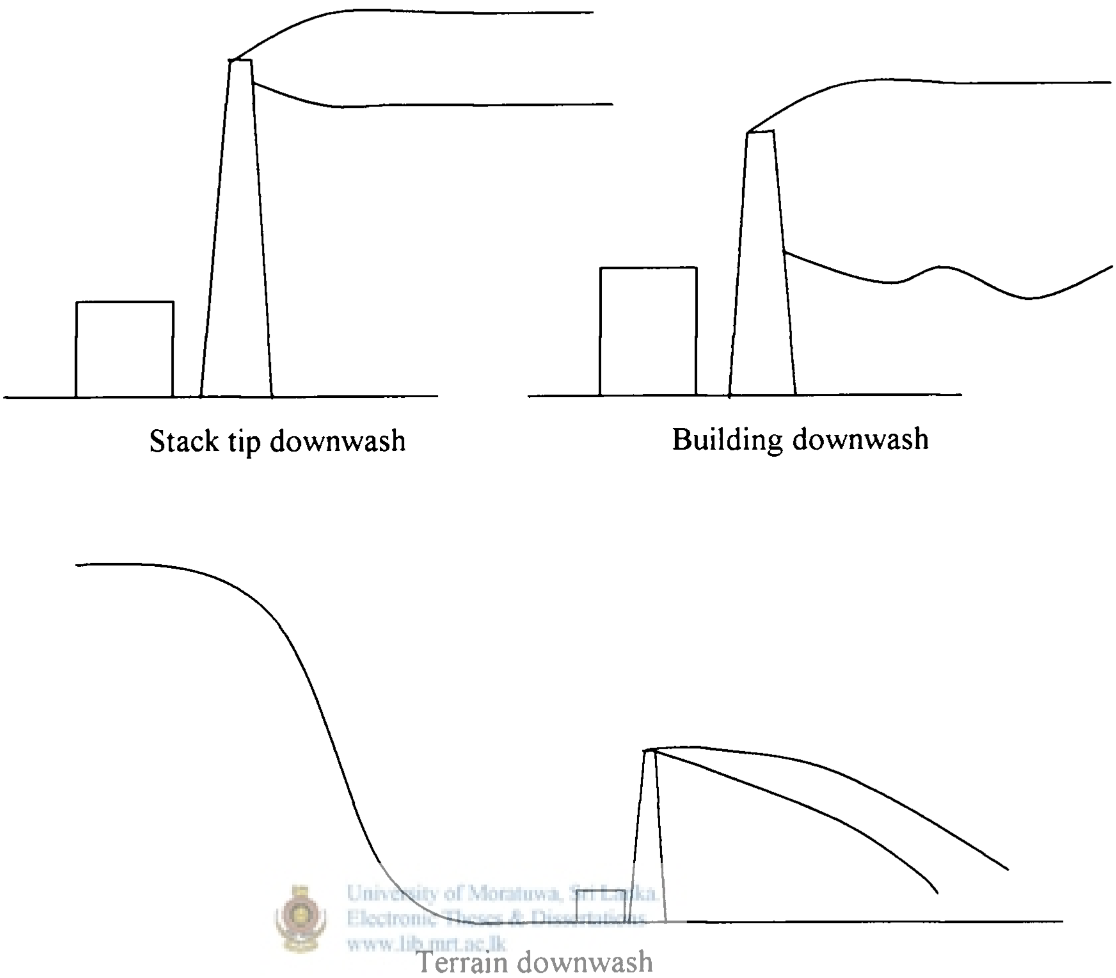


Figure 2.12: Downwash types

Stack tip downwash

Stack tip downwash occurs when the ambient wind speed is high enough relative to the exit velocity of the plume so that some or the entire plume is pulled into the wake directly downwind of the stack. The creation of the wake is illustrated below.

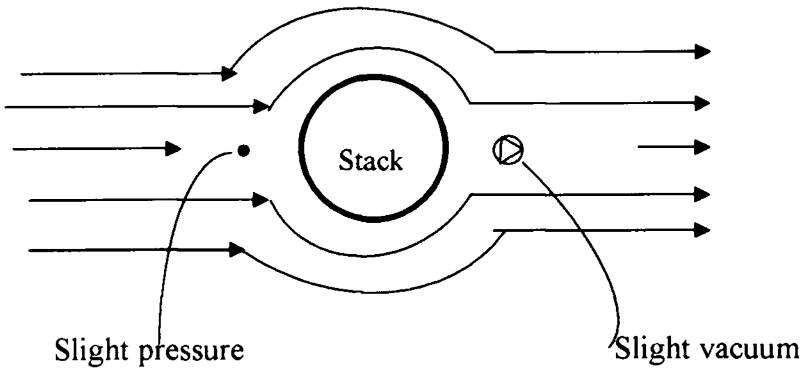


Figure 2.13: The creation of the wake

This downwash has two effects on the plume rise.

- The pollutants drawn into the stack wake leave the stack region at a low height than that of the stack and with a lower upward velocity
- Downwash increases the plume cross section, which decreases the concentration

To avoid this situation stack height has to be designed according to the following relationship.

$$h_{std} = 2d_s\{(v_s/u_s) - 1.5\} \qquad (2.6)$$

v_s emission velocity

u_s wind speed at stack height

d_s diameter of the stack

If $(v_s/u_s) > 1.5$ stack tip downwash is avoided

$(v_s/u_s) < 1.0$ downwash will probably occur

For intermediate values of (v_s/u_s) downwash may occur depending on the ambient conditions.

Building downwash

Large structures surrounding a stack also affect ambient wind conditions. The boundaries of the wake region resulting from surrounding structures are not sharply determined. They depend on the three dimensional characteristics of the structure and are time dependent. Depending on the building geometry and the direction of the wind, the extent of distortion changes. Generally a cylindrical structure has little influence on the wind flow compared to a rectangular structure.

As a rule of thumb to avoid the building wake stacks are designed to have 2.5 times the height of the tallest building in the vicinity (Rao, 1996). Other than this more logical methods developed by USEPA and other institutions are available too.

Terrain downwash

Downwash can also be caused by local topography. Large mountains can change the normal wind pattern in an area. If a stack is located closely downwind of a hill above stack height, the air flowing off the hill can cause the plume to impact closer to the stack than normal.

Modeling of these situations often requires physical models in wind tunnels.

2.4 Cement manufacturing industry

Cement is a finely ground, usually grey colored mineral powder. When mixed with water, cement acts as a glue to bind together the sand, gravel and crushed stone to form concrete, the most widely used construction material in the world.

Cement manufacturing is a high energy consuming process. Limestone and other materials containing calcium, silicon, aluminium and iron oxides are crushed and milled into a raw meal. This raw meal is blended and then heated in the pre-heating system which consists of cyclones to start the dissociation of calcium carbonate to oxide. The meal goes further into the kiln for heating and reaction between calcium oxide and other elements to form calcium silicates and aluminates at a temperature up to 2000 ^{0}C and so-called clinker is formed. The cyclone system is attached to the rotary kiln by a riser duct. Secondary fuel is fed to the riser duct, the main fuel mixture, coal or petcoke, fires the kiln. Reaction products leave the kiln as a nodular material called clinker. The clinker will be interground with gypsum and other materials to cement.

Table 2.3: Basic raw materials of Portland cement

Basic Chemical Components of Portland Cement	Typical Raw Materials
Calcium (Ca)	Limestone ($CaCO_3$)
Silicon (Si)	Sand (SiO_2)
Aluminum (Al)	Shale, Clay (SiO_2, Al_2O_3, Fe_2O_3)
Iron (Fe)	Iron Ore/Mill Scale (Fe_2O_3)

The proportions of raw materials are generally as given below (Table 2.4).

Table 2.4: General compositions of basic raw materials

Raw material	% Range
CaO	62- 67
SiO_2	20- 24
Al_2O_3	4- 7
Fe_2O_3	2- 5

The higher the lime content in the raw material mix, the higher is the flame temperature required for clinkering.

The minor constituents such as MgO, Mn_2O_3, P_2O_5, TiO_5, alkalines and chlorides should not be present in undesirable quantities. Average compositions of those are,

Table 2.5: General compositions of minor constituents

Raw material	%
MgO	3.5
Mn_2O_3	0.5
$K_2O + Na_2O$	0.6
SO_3	0.6- 0.8
P_2O_5	0.6
Chloride	0.015- 0.02

Cement manufacturing can be done in following methods.

- Wet Process
- Dry Process - 74% of cement produced
- Preheater/ precalciner process

In wet process it is easier to control chemistry and better for moist raw materials. But as the final product is a dry powder wet process consumes a lot of energy. This is for the evaporation of 30% or more slurry water.

The dry process kilns have less fuel requirements. The main steps in the manufacturing process are as follows.

i. Quarry and raw material preparation

Quarry : Limestone and other raw materials are extracted using drilling and blasting techniques.

Crusher : The quarried material is reduced in size in crushers by compression or impact.

Transport : The crushed raw material is transported to the cement plant, mainly using conveyors or rail wagons.

ii. Clinker production

Mixing bed : The limestone, clay and alternative raw materials are mixed and homogenized.

Dust filter : Bag house filters or electrostatic precipitators remove particles from kiln and mill exhaust gases.

Raw mill : The homogenized raw materials are milled and dried in a mill.

Preheater : The raw material is preheated before entry into the kiln.

Kiln : At flame temperatures up to 2,000° C and materials temperatures up to 1,450° C the raw materials are transformed into clinker minerals.

Clinker cooler : The molten cement clinker is rapidly cooled.

iii. Cement grinding and distribution

Clinker silo : Cooled clinker is stored in preparation for grinding on site or transport to other sites.

Cement mill : Cement clinker is ground with around 5% of gypsum and other alternative cementitious materials such as slag or fly ash to form the final cement types.

Logistics : Cement is transported in bags or as a bulk powder.

Preheater or precalciners further enhance fuel efficiency and allow high production rates.

2.5. About the company- Holcim Lanka Ltd

Holcim (Lanka) Ltd operates the only fully integrated cement plant in Sri Lanka, in Puttalam. It also operates a Grinding plant in Galle and several packing units located in different areas of the county. The company currently employ nearly 600 people at all levels.

Holcim (Lanka) Ltd sells 1 million tons of cement each year, marketed under the brand name - Holcim and generates annual revenues of approximately LKR 6 billion (60 million USD). Depending on the customer requirements the company produces several varieties of cements for making concrete, masonry work and for finishing.

The company vision

We are the leading and preferred supplier of cement to build foundations for Sri Lanka's future.

The company mission

To be Sri Lanka's most respected and attractive company - creating value for all our stakeholders

The company goals are

- Continually set the highest standards of customer satisfaction in the industry
- Secure the strongest competitive position in the markets
- Partner with suppliers to deliver value-for-cost procurement for the Group and the customers
- Be recognized as an employer of first choice
- Empower the employees and integrate them fully into the global network
- Selectively grow worldwide portfolio of companies
- Demonstrate commitment to sustainable development
- Be acknowledged as a valued and trusted partner in the community

- Be the most recommended stock in the industry

The company has extended their activities towards the environmental responsibility and making a better environment for the future. The relevant projects conducted during the year 2004 are,

- Eliminating dust emissions from the operations by installing a Bag Filter system
- Implementing systems to measure and monitor effects of the operation on the community and the environment
- Implementing an internationally recognized Environmental Management System (EMS) within the plants
- Waste co-processing
- Tree planting and other community projects

Holcim (Lanka) Ltd. states that it supports the nation's pursuit of sustainable development and acknowledges the social responsibility to help create a safer and healthier environment. As a member of the Holcim Group, the company is committed to the principles of global environmental and social policies. In pursuing business objectives, the company is committed to produce cement of consistent quality that meets local and internationally accepted standards. Amongst the highest priorities are care for the environment, and the health and safety of employees and the neighboring communities.

The company has implemented an integrated quality and environmental management system compliant with internationally recognized standards. To continually measure and improve the performance and to ensure the effectiveness of the management system, the following policies are being followed;

- Apply a pragmatic compliance with laws, regulations and standards applicable to the products and operations; cement industry initiatives and other requirements the company subscribes to; and the needs of the integrated management system;
- Promote responsible development and use of natural resources by adopting appropriate and cleaner technologies;

- Implement effective controls to prevent or minimize the release of pollutants to the environment in all our operations;
- Optimize the use of fuels, raw materials, water, electricity, and other resources, and where appropriate, reuse, recycle and dispose of all wastes generated through safe and responsible methods;
- Implement effective waste management programs;
- Set and review periodically the quality and environmental objectives and targets, and provide adequate resources and controls to ensure effective implementation;
- Provide employees appropriate training and support thereby maintaining a competent workforce that is quality and environment conscious;
- Promote quality and environmental awareness among employees, suppliers, contractors and neighboring communities;
- Implement effective security control systems to ensure protection of personnel and physical resources;
- Communicate quality, environmental programs and activities to all stakeholders, including employees, the public and relevant authorities.

2.6 Air pollution potential from cement manufacturing

Cement and concrete as well as other building materials are essential to development of human society, but their production processes can have significant impacts on the environment. On a global level, the cement industry consumes great amounts of energy and is among the biggest producers of carbon dioxide, its emissions representing 5% of worldwide emissions. Cement production processes involve emissions of pollutants as well as other local pollution such as noise and dust.

The limestone quarries from which the principal raw material of the cement manufacturing process is extracted can also generate pollution for neighboring populations such as landscape degradation and traffic and impact biodiversity. Proper and

improved quarry management systems help to minimize noise, transport and visual impact, to reduce the use of natural resources and to optimize quarry rehabilitation.
Clinker production requires intensive use of raw materials and energy, and also results in emissions to the atmosphere, the most significant being CO_2. Reduction of demand for natural resources and CO_2 emissions per tonne of product can be achieved by replacing fossil fuels and raw materials with waste and industrial by-products.

Apart from CO_2, cement production emits dust and several gases that are submitted in most cases to stringent regulations. In modern cement plants these emissions are reduced to almost zero by improving processes and applying specific mitigation techniques.

The NO_x are generated by fuel combustion at high temperatures. In high concentrations they contribute to the formation of acid rain and photo-chemical oxidant smog and can create respiratory problems. Emissions levels could be reduced through modernizations of the process and addition of ammoniac which are sometimes taken from industrial waste in to the kiln.

Dust is generally of a mineral nature and in some instances is an aggravating factor of respiratory problems. Dust released at the plant chimney stack (< 10 μm in diameter) is only one type of dust emitted, but is the most easily measured.

Another type of dust is fugitive dust, coming from quarrying and transportation. This dust affects the neighborhood more directly and contributes to the increase of ambient air dust levels.

These are more difficult to measure but various mitigation techniques like spraying roads and stored materials with water and enclosing storage sites can be applied to have minimum impacts on the environment as well as the society.

The SO_x s can be released at the stack when natural raw materials contain sulphur in mineral form (like iron sulphide also called pyrite). In high concentrations SO_x may create respiratory problems and is a major gas contributing to the formation of acid-rain.

In the last few years' sources of micro-pollutants such as dioxin, furans, mercury, and other substances have drawn the attention of the international community. Due to the nature of the cement process, the emissions of dioxins and furans are typically in very small quantities that are well under regulatory limits. Nevertheless, they represent an important cause of concern for many stakeholders, especially when waste fuels are used, even if related emissions do not significantly differ from conventional fuels-related emissions. When a cement kiln is used as a hazardous waste incinerator it is better to carry out analysis for the evaluation of these substances, even though it is a costly business, to convince the stakeholders about the environmental friendliness of the operation. However this is one of the methods approved by the Stockholm Convention for the destruction of POPs. It is much more environmentally friendly when compared with some of the current practices of open dumping and uncontrolled burning of hazardous wastes being carried out in Sri Lanka.

CHAPTER 3: APPLICATION OF A MODEL TO PREDICT AIR EMISSIONS

Out of the models described in predicting air emissions in the earlier chapter, the AUSPLUME model was selected for achieving the objectives of this study. It has been used by many countries for regulatory purposes and has a wide variety of applications. Further its results can be easily interpreted too.

The main reasons for selecting AUSPLUME model for this study are as described below.

.

- → It has a range of options and many combinations of parameters can be analysed. (Stack dimensions, plume exit flow rate, plume temperature, receptor elevation)
- → A strong meteorological data file consisting hourly data for 365 days is required and therefore the accuracy of the results should be higher than with other model (provided the meteorological data are correct)
- → The results can be easily interpreted
- → It has proven results worldwide

APPLICATION OF AUSPLUME

The data required by the AUSPLUME model and the selection of other parameters required for the specific situation is described below.

3.1 Simulation title

The title required in the results output should be given at the start of AUSPLUME model. It may consist of the specific pollutant being modeled, source and time period considered.

3.2 Meteorological data file

Meteorological data required for the calculation are;

- wind velocity
- turbulence conditions (stability class)
- mixing height
- ambient air temperature

On site measurement of the hourly parameters are required over a period of one year. If these cannot be obtained directly from a weather monitoring station it is possible to prepare a meteorological data file using the available representative data. Sample meteorological file is given in Annexure 1.

The methodology of preparing of the meteorological file is described below.

3.2.1 Wind speed

The wind velocity is represented in each calculation by a uniform, constant wind speed and direction. To ensure that all likely combinations of wind velocity and other meteorological conditions are covered, the calculation should be repeated for each of the 8760 hourly wind velocity readings in a year of real data.

The data available at the Meteorological Department of Sri Lanka at the Palavi weather monitoring station (which is the closest to the Puttlam Cement plant) consists of 3 hourly wind velocities. In the preparation of the met file it was assumed that the velocity varies linearly in the 3 hr period and hourly velocities were calculated accordingly. Given below is the calculated hourly wind data on 1st of January 2003. The data for the remaining 365 days were also calculated in a similar manner.

Table 3.1: Variation of wind speed during the day

Hour of the day	Wind speed (m/s)
1	0.6
2	0.6
3	**0.6**
4	0.4
5	0.2
6	**0.0**
7	0.0
8	0.0
9	**0.5**
10	0.5
11	0.5
12	**0.5**
13	1.3
14	2.0
15	**2.7**
16	1.9
17	1.2
18	**0.5**
19	0.5
20	0.5
21	**0.5**
22	0.5
23	0.5
24	**0.5**

The values given in bold letters are the available values at the meteorological department.

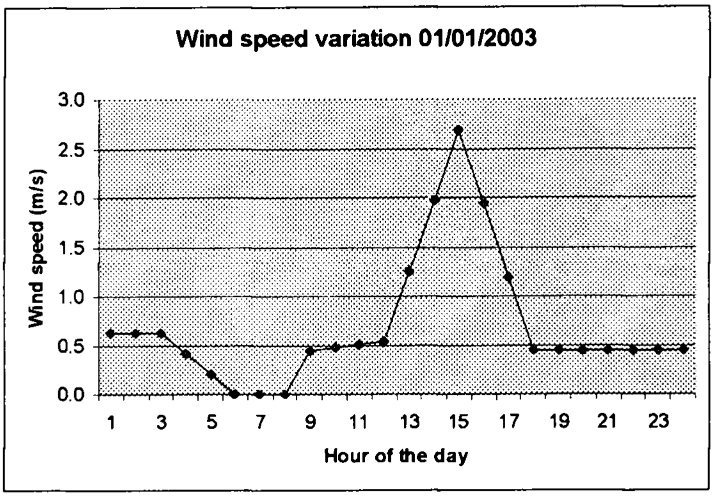


Figure 3.1: Variation of wind speed during the day

The AUSPLUME model requires the hourly wind speed at the elevation of the discharge. This is computed with the use of the 'Power law' which was described in Chapter 1 (Equation 1.4).

3.2.2 Wind direction

Measurements of the wind directions are used to compute the hourly mean wind direction, the three minute fluctuations in the wind direction and the sixty minute fluctuations in the wind direction.

The wind direction data available with the meteorological department (Log book) are 3 hourly data. In the calculations it was assumed that the wind direction remains constant for three hours and therefore, a step variation in the wind direction. This is a potential source of error which cannot be helped due to the limitation of data available but will have to be considered when drawing conclusions from the out put of the model.

Table 3.2: Variation of wind direction (degrees from North) during the day 01/01/2003

Hour of the day	Wind direction (Deg)
1	45.0
2	45.0
3	**45.0**
4	45.0
5	45.0
6	**0.0**
7	0.0
8	0.0
9	**45.0**
10	45.0
11	45.0
12	**67.5**
13	67.5
14	67.5
15	**337.5**
16	337.5
17	337.5
18	**337.5**
19	337.5
20	337.5
21	**0.0**
22	0.0
23	0.0
24	**45.0**

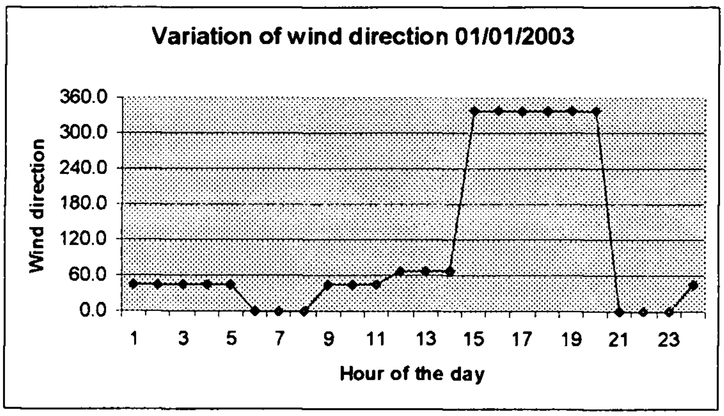


Figure 3.2: Variation of wind direction during the day

The vectorial average of the sequence of the wind direction measurement made should be computed in obtaining the hourly or 3- minute mean wind directions. The arithmetic average may be used provided steps are taken to avoid the error which can arise when wind fluctuates about the 360^0- 0^0 sector. Arithmetic average of wind directions was taken in this study.

3.2.3 Stability categories

The model uses a Pasquill category in classifying the ambient turbulence. (AUSPLUME user manual)

Class A	=	extremely unstable conditions
Class B	=	moderately unstable conditions
Class C	=	slightly unstable conditions
Class D	=	neutral conditions
Class E	=	slightly stable conditions
Class F	=	moderately stable conditions

This classification system uses meteorological parameters such as wind speed, day time solar radiation and night time cloud cover. They are indicative of the relative strength of the two mechanisms for generating atmospheric turbulence namely shear stress at the earth's surface, heat flux into or away from the earth.

The classification was done using the Table 2.1. In the classification it was assumed that the sunrise is at 0600 hr and the sunset is at 1800 hr. No assumptions were made in computing the stability class as it varies with the wind speed and the time of the day. Stability class for each hour of the day was determined based on the wind speed and the time of the day (see Table 3.1).

Table 3.3: Variation of the stability class during the day

Hour of the day	Stability class
1	E
2	E
3	E
4	E
5	E
6	E
7	A
8	A
9	A
10	A
11	A
12	A
13	A
14	A
15	B
16	A
17	A
18	A
19	E
20	E
21	E
22	E
23	E
24	E

3.2.4 Mixing height

For the plume calculation procedure, the mixing height must be specified at hourly intervals. Ideally the height could be obtained from on- site measurements by an acoustic sounder, but in most cases it is computed using already prepared data tables. Mixing heights were calculated using Table 2.2. Given below are the mixing heights during 01/01/2003

Table 3.4: Variation of the mixing height during the day

Hour of the day	Mixing height (m)
1	5000
2	5000
3	5000
4	5000
5	5000
6	5000
7	5000
8	5000
9	300
10	300
11	300
12	300
13	1000
14	1300
15	1400
16	1300
17	600
18	300
19	5000
20	5000
21	5000
22	5000
23	5000
24	5000

For wind speeds below 0.5 m/s the mixing height is not available in the Table 2.2. Therefore the previous value was assumed to remain during that time as well, which is a possible cause of errors in the final results.

3.2.5 Temperature

Similar to the other parameters hourly ambient temperatures are also required for a full year. Values available at the meteorological department are daily maximum and minimum temperatures. From those values the average was taken and assumed it to be constant through out the day.

01/01/2003 Maximum temperature = 30.2^{0}C

Minimum temperature = 20.4^{0}C

Average temperature = 25.3^{0}C

Table 3.5: Variation of ambient temperature during the day

Hour of the day	Temperature (deg C)
1	25.3
2	25.3
3	25.3
4	25.3
5	25.3
6	25.3
7	25.3
8	25.3
9	25.3
10	25.3
11	25.3
12	25.3
13	25.3
14	25.3
15	25.3
16	25.3
17	25.3
18	25.3
19	25.3
20	25.3
21	25.3
22	25.3
23	25.3
24	25.3

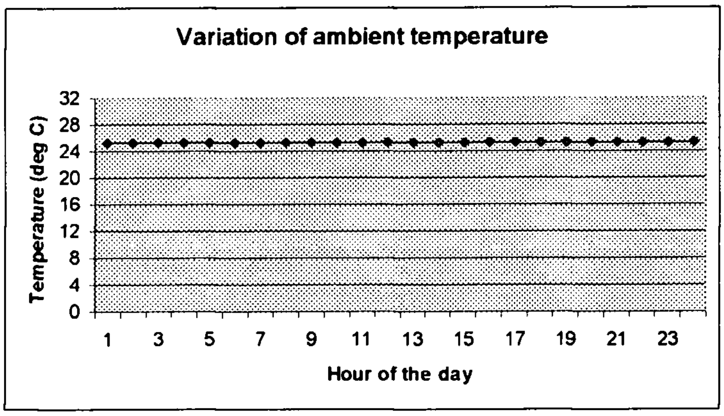


Figure 3.3: Variation of ambient temperature during the day

3.3 Model parameters

The following model parameters are considered in this section.

Emission rate units: The units are given in the model and the required unit can be selected. The units available are g/s, kg/hr, tones/year, ovu/s and ovu/min.

Concentration units: Required unit can be selected from the given units namely, $\mu g/m^3$ and mg/m^3.

Conversion factor: This is automatically appearing when the above two units are selected. As for an example if the emission rate is in g/s and the concentration is in $\mu g/m^3$ the conversion factor is 1000000.

Background level: If the background concentration of the specific pollutant selected is a variable the variable concentration file has to be entered. If it is a constant that can be directly entered. In this study the background concentration was taken as zero because the idea was to find out the contribution from the stack.

Output type : The user can decide whether the output should be in terms of concentration or deposition.

Depletion options: Whether wet or dry conditions to be considered. For wet depletion rainfall data has to be included in the meteorological data file.

Since the precipitation in the Puttlam district is very low, dry deposition was considered.

Terrain effects: What type of terrain effect to be considered or whether it is neglected has to be decided at this stage.

Puttlam area is almost flat and therefore, the terrain effects were neglected.

3.4 Source information

First, the source has to be selected. Available sources are stack, area source and volume source. Source emission information can be given either through the user interface or by an external data file. As only the stacks at Puttlam Cement plant were going to be considered, given below are the information required for the stack source.

Source ID : A name can be given to the stack which is going to appear in the output file. If several sources are considered this identification name is very much important.

Source coordinates : The source coordinates in meters can be given relative to an arbitrary point in the site plan or specified in map coordinates. If terrain effect is considered same coordinates system has to be used with them.

For easy manipulation the stack location was considered as the origin in this work.

Source characteristics: The height of the stack, stack diameter, temperature of the existing plume and the exit velocity are given at this stage. The first two are fixed values for a stack and the latter two are variables or time dependent.

Building wake/ dimensions : If the effects due to the buildings in the vicinity are to be considered the dimensions of the buildings are to be given. Building wakes can be ignored if the stack height is 2.5 times the building height.

Deposition : Gravitational settling or surface scavenging can be estimated when this option is selected. But it is required to have the particle diameter and particle density distribution.

Emission rates : The pollutant emission rates are to be given at this stage. If it is constant the value can be directly given or otherwise variable emission rate data file has to be provided. In this study the emission rate was considered as constant.

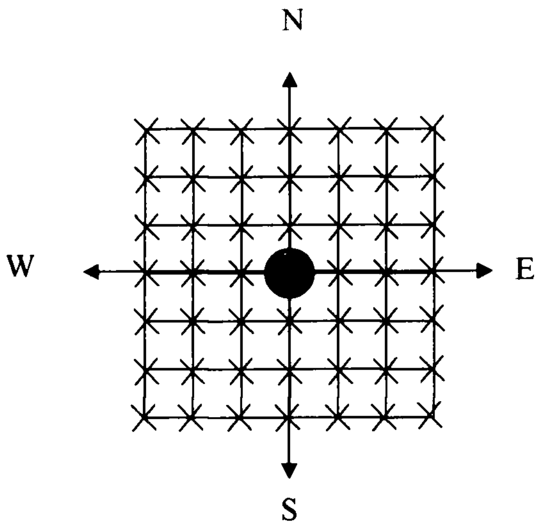
3.4.1 Receptor information

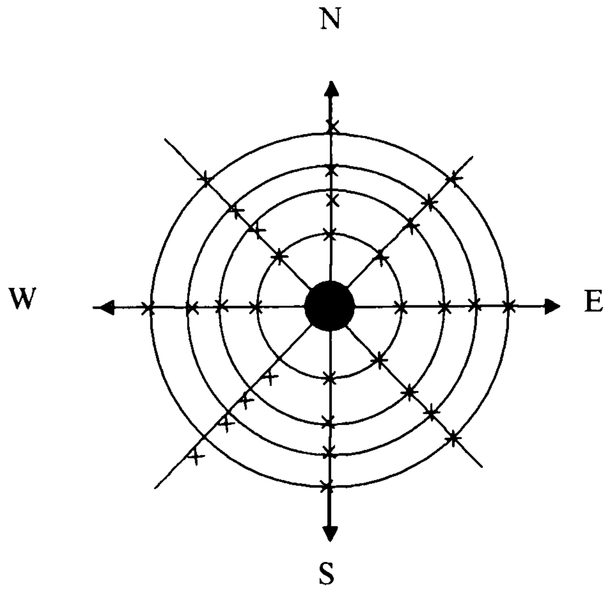
Receptors are the locations at which the concentrations or depositions are estimated by AUSPLUME. The receptor can be either gridded or discrete.

Gridded receptors : The grid can be cartesian or polar. The model can develop the grid automatically either at uniform spacing or irregular spacing depending on the requirement. It is required to specify the height above the ground level at which the grid has to be considered.

The polar grid is used when there is a single source or when the sources are close together when compared with the distance to the closest receptor.

Cartesian coordinated are used when the sources are not concentrated to a central point.





Source   X Receptor

Figure 3.4: Cartesian receptor grid   Figure 3.5: Polar receptor grid

Discrete receptors : Discrete receptor sites are the locations of specific interest. The interest can be because of the sensitive nature or the functional importance of the location or the elevated locations like hills, buildings or residential areas. These points can be individually entered and the coordinate system can also be initially selected.

3.4.2 Land use category

The land use categories given in the model are, hills, high-rise, industrial, commercial, residential, forest, rolling rural, flat rural, flat desert and water. Once the relevant category is selected the surface roughness will automatically appear.

If the value is known it can be directly entered as well.

3.4.3 Averaging times

Averaging time for the constituent being modeled has to be selected at this stage. This could be done based on the health standards or the regulatory requirements.

The averaging times may vary from,

- Short averaging times eg. minutes in the case of nuisance odors or the design ground-level concentrations of many industrial emissions
- Moderate averaging times for pollutants with acute health effects specified by air quality standards eg. 1-hour or 24-hour sulfur dioxide standard
- Long-term averages for pollutants that have chronic or cumulative environmental effects, eg. Fluoride, lead or carcinogens.

3.4.4 Output options

Output options are of three types. They are print files, concentration contours and frequency contours.

All meteorological data, every concentration or deposition, highest or 2nd highest tables, 100 worst cases tables are the allowed printed outputs.

The gridded concentration data file contains the location and concentrations (depositions) calculated for each receptor grid location. This file does not include the discrete receptor locations.

The gridded frequency data file consists of the frequency with which predicted concentrations (depositions) exceed some user defined level at each of the gridded receptor locations.

3.5 Other parameters

3.5.1 Dispersion curves

Plume dimensions are calculated at any point downwind of the source depending on the parameters selected at this stage. Horizontal dispersion curves and vertical dispersion curves have to be specified and the consideration is given to stack height whether the stack is higher or lower than 100m.

If the averaging times decided are less than one hour, AUSPLUME model estimates both the horizontal and vertical plume spread from the Pasquill-Gifford dispersion curves in the determination of σ_y and σ_z. The two curves are given in Annexure 5 (Kiely, 1997).

When wind direction shear effects are present the previously described curves need to be adjusted for these effects. If the earth surface is flat like in Puttalam these effects can be neglected.

3.5.2 Plume rise

The AUSPLUME default configuration for 'Plume Rise' parameter assumes:

- the gradual rise of a buoyant plume
- plume downwash may occur behind a stack
- reasonable values for plume entrainment
- reasonable values for potential gradients
- partial penetration of elevated inversions will not occur.

These can be overwritten depending on the situation.

Gradual plume rise

If this option is not selected the model to assume the plume is at the final plume height everywhere when calculating ground-level concentrations, rather than calculating plume height as a function of downwind distance. The gradual plume rise mechanism is physically realistic but mathematically simplistic one is the final plume rise.

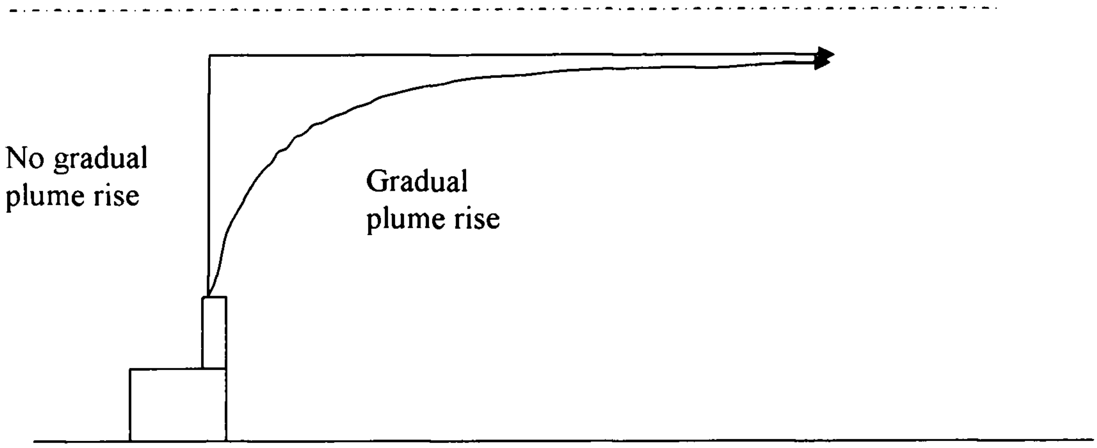


Figure 3.6: Plume rise options

Stack-tip downwash

AUSPLUME allows for the downwash effects of chimney wakes. The reduction in plume height is never more than three chimney diameters and so usually makes little difference to the results.

Partial penetration of elevated inversions

Most Gaussian plume models assume that elevated inversions contain such weak vertical turbulence that plumes within them never penetrate to the ground, and conversely, that plumes in the mixed layer below cannot penetrate upwards through the inversion base. AUSPLUME provides an option for simulating the partial penetration of buoyant plumes through an elevated inversion.

Entrainment coefficients for adiabatic and stable lapse rates

Plume turbulence entrains ambient air into the plume. This effect reduces the plume rise and the final plume height. AUSPLUME assumes that the default entrainment coefficients used in the calculation of the plume rise parameters are equal to 0.6.

Assumed potential temperature gradient in elevated inversions

AUSPLUME provides an option to allow partial penetration of an elevated buoyant plume through an inversion base. If this option is selected, AUSPLUME will calculate the plume rise through a stably stratified layer with an assumed potential temperature gradient.

3.5.3 Wind speed categories

AUSPLUME reads hourly wind speeds from the meteorological data file. However, wind profile exponents and the option that allows emission rates to vary by stability and wind speed are not considered as continuous functions of wind speed by the model. Emission rates and wind profile exponents are assigned on the basis of six intervals of the recorded wind speed. The default wind speed categories can be modified for entering specific on-site wind profile exponents.

The default wind speed categories are:

Table 3.6: The default wind speed categories

	1	**2**	**3**	**4**	**5**	**6**
m/s	0 - 1.54	1.54 - 3.09	3.09 - 5.14	5.14 - 8.23	8.23 - 10.8	>10.8

3.5.4 Wind profile exponents

The wind profile exponents (Equation 2.5) are not considered to be continuous functions of the observed wind speed read from the meteorological data file. The exponents are instead assigned on the basis of six wind speed intervals.

"Irwin urban" exponent scheme in the model can be selected for regions such as commercial, residential or industrial areas where surface roughness and heat flux or both encourage atmospheric turbulence. "Irwin rural" exponents should be used in areas with low surface roughness, such as rolling grazing areas.

The default wind profile exponents are as given below.

Table 3.7: The default wind profile exponents

Stability category	A	B	C	D	E	F
Irwin rural	0.07	0.07	0.10	0.15	0.35	0.55
Irwin urban	0.15	0.15	0.20	0.25	0.40	0.60

3.5.5 Miscellaneous parameters

The parameters falling into this category are;

- Building wake effects
- Default decay coefficient
- Anemometer height
- Sigma- theta averaging period
- Meteorological sight roughness height
- Smooth stability class changes?
- Stability class adjustments
- Building wake algorithms

Include building wake effects

This option allows canceling the wake effects of buildings whose dimensions are specified in the source characteristics screen.

Default decay coefficient

In AUSPLUME, the exponential decay of pollutants is modeled by simply multiplying the computed concentrations by the factor $e^{kx/U}$ where

k	decay coefficient
x	downwind distance
U	wind speed at plume height

A single default value for k can be specified for all hours, or a separate value can be specified in the hourly meteorological data file. The hourly value may be appropriate, for example, for simulating rain out.

For a conserved species, the default decay coefficient should be set to zero.

Anemometer height

The anemometer height refers to the instrument that recorded the wind information used to prepare the hourly meteorological data file. The recommended observation height used by many weather services and also in this study is 10 m.

Sigma- theta averaging time

The sampling time for sigma theta values refers to the duration over which wind direction measurements were taken when determining the sigma theta data stored in the hourly meteorological data file. Sigma theta averaging time should match with the concentration averaging time specified in the simulation.

Roughness height at wind vane site

This is the aerodynamic roughness at the wind measurement station selected to provide data for the meteorological data file. The default value used by the program is 0.3 m.

Smooth stability class changes

AUSPLUME reads hourly atmospheric stability categories from the meteorological data file. From one hour to the next, these stability categories are capable of changing by more than one class, eg. stability may change from stability class F to D.

However, if the option to smooth stability class changes is selected, then changes to the atmospheric stability class are limited to one category per hour. In the example above, stability would change from F through E to D.

Stability class adjustments ("urban modes")

The assumption behind this mode is that the high surface roughness and heat island effect of a dense urban area results in less stable atmospheric stabilities than would be otherwise expected.

If urban mode 1 is selected, stable classes (E and F) are immediately reassigned to neutral stability class (stability D).

Urban mode 2 reassigns class F conditions to class E. The model then computes the dispersion coefficients for classes B to E using the formula for the next less stable class, eg. class B is replaced by A, class C by B etc.

CHAPTER 4: ANALYSIS OF THE FATE OF STACK EMISSION USING AUSPLUME

The AUSPLUME model was applied to a hypothetical stack emission. The meteorological data file developed for Puttlam area described in Chapter 2 of this report was used in this application. Initially, various hypothetical emissions from this hypothetical plant were considered and the fates of the pollutant were determined. These analysis were done to see the applicability of AUSPLUME in the Environmental Impact Assessment (EIA) process in Sri Lanka. The analysis is described in the first part of this chapter.

Some real emission data from the same plant were applied in the same model-AUSPLUME and the fate of the pollutants in the atmosphere was determined. The fate of emissions before and after installing a new dust handling system has been analyzed here. This application is described in the second part of this chapter.

4.1 Applicability of AUSPLUME in Environmental Impact Assessment- a hypothetical case study

Dispersion models can be used in the EIA process for the prediction of pollutant dispersion from a stack or a group of stacks. This type of models has been used in Sri Lanka in preparing EIAs for major power plant projects. A list of them is given in Annexure 2.

A hypothetical constituent in the stack emissions is considered in this work. The hypothetical data related to this constituent and the stack dimensions used are shown in Table 4.1. The considered constituent can be any non reactive one which would not be gravitationally settled. The averaging time considered was 8hrs. The AUSPLUME model can estimate the worst hundred cases of the pollution by the constituent concerned in selected locations under the given meteorological data conditions. A sample output file is given in Annexure 3. These hundred maximum concentration points of the constituent distributed along the plume centerline are calculated for varying parameters shown in Table 4.1. The results of these estimates are discussed in this section.

Table 4.1: Stack dimensions and Emission Data for the Hypothetical Constituent in the Stack Emission

Parameter	***Value***
Height of the stack (m)	80
Diameter (m)	1.4
Exit temperature (^{0}C)	120
Exit velocity of the plume (m/s)	20
Emission rate of the constituent (kg/hr)	0.0125

The Figure 4.1 gives the ground level maximum concentrations of the constituent along the plume centerline estimated using AUSPLUME model for an emission rate of 0.0125 kg/h of the constituent. The other parameters required for this estimation are shown in Table 4.1.

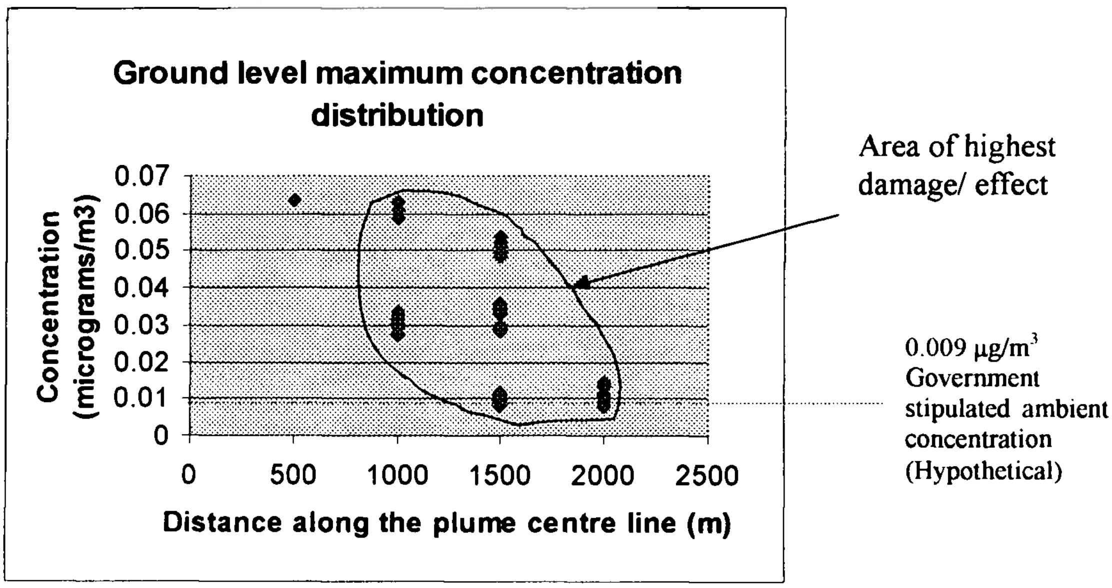


Figure 4.1: Ground Level Maximum Concentration for an Emission from a Stack Height 80m and Plume Exit Velocity 20m/s

The area where most of the highest concentration values are distributed is considered as the "area of highest damage or effect".

The Figure 4.1 clearly shows that the area between 1000 m - 2000 m is the area where most damage can be expected from the substance considered through out the year. These results can be used to decide on the extent of the buffer zone. A buffer zone is an area of appropriate size around the plant that is essentially kept to avoid any possible adverse effect, especially to the community outside. If the concentration of the constituent considered is above the government stipulated level there would be a necessity of extending the buffer zone up to the distance of acceptable level. But if this distance is going to be very long necessary steps should be taken to reduce the emission load. As for an example consider the constituent in Figure 4.1. Assume that the government stipulated ambient concentration of this constituent is 0.009 $\mu g/m^3$. It can be seen from figure 4.1 that it is better if a buffer zone of about 2 km can be kept where the industry can grow plants and maintain a nice environment. However, this may not be possible due to the scarcity of land. Therefore, other possible alternatives such as changing the stack dimension to have low ground level downwind concentrations, installing air pollution control equipment or improve the process to reduce the emission load can be considered. Further, if the government stipulated ambient concentration is assumed to be 0.06 $\mu g/m^3$, the buffer zone can be limited to 1 km.

The Figure 4.2 given below shows the downwind concentration parameters at an elevation of 30 m from the ground level with all the other conditions same as at Table 4.1.

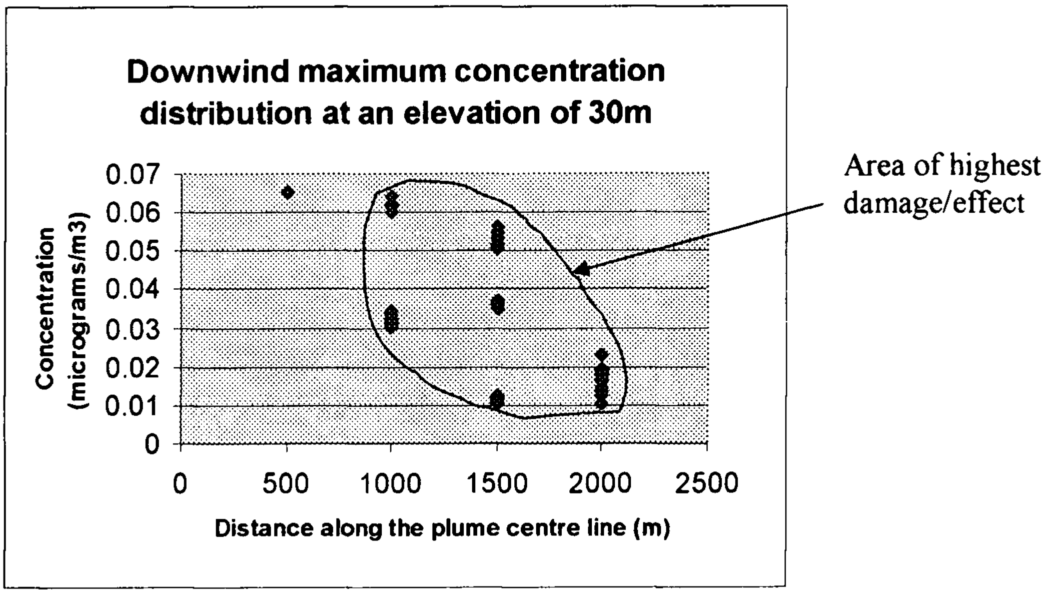


Figure 4.2: Maximum Concentration at a 30m Elevation for an Emission from a Stack Height 80m and Plume Exit Velocity 20m/s

The concentration distributions in both Figure 4.1 and Figure 4.2 are almost the same other than the differences in the values. The area of the highest damage is also similar in both cases. The concentrations at the same distance but at a higher elevation are greater than those at the ground level. Therefore, it is obvious that effects to a high-rise building are more. The maximum height of the tallest building can be built in the vicinity of the stack can be taken as 30m, because the height of the nearby tallest building should not exceed 0.4 times height of the stack (Rao, 1996). If the construction is more than 32m in height there will be building wake effects. Building wake effects can be described as a low-pressure region, which can occur when wind passes a high rise building. If a stack is close by, the plume may spread in this low-pressure region making the pollutant concentration higher.

The Figure 4.3 shows the downwind concentration parameters at ground level for a plume exit velocity of 25 m/s with all the other conditions as in Table 4.1.

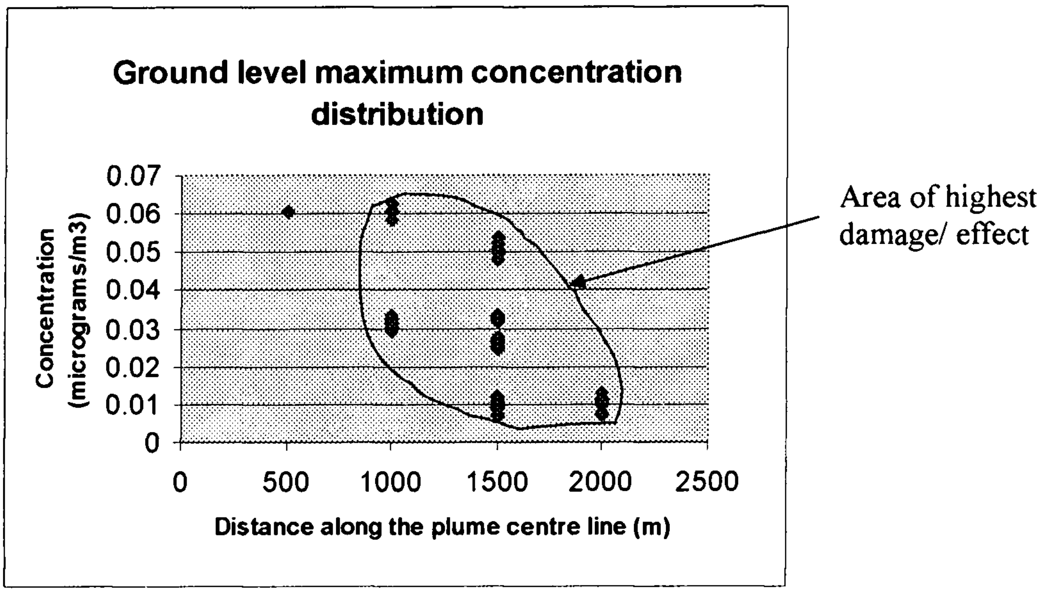


Figure 4.3: Concentration at Ground Level for an Emission from a Stack Height 80m and Wind Velocity 25m/s

According to the above graphs it is clear that the highest concentration distribution is confined to the same area in the elevated level and ground level although plume exit velocity is increased in 5 m/s. This could be due to the meteorological conditions considered in all above cases being the same. Further, the concentration changes that can occur when the pollutant load is changed by any manner such as changes in exit temperature, emission concentration or stack dimensions can also be studied using the AUSPLUME model.

The effect of plume exit velocity on the dispersion of pollutants can be further explained as follows. The exit velocity of the plume is changed while keeping stack height, stack diameter, exit temperature and the meteorological conditions similar.

Table 4.2: Maximum ground level concentration for varying plume exit velocities

	Maximum Concentration (μg/ m^3)				
Plume exit velocity (m/s) →	12	16	20	24	28
Downwind distance (m) ↓					
200	0.0046	0.00303	0.00202	0.00135	0.000907
300	0.0342	0.0279	0.027	0.0152	0.0124
400	0.086	0.0822	0.0438	0.0379	0.0346
500	0.109	0.108	0.0634	0.0613	0.0598
600	0.101	0.101	0.0655	0.0653	0.0651
700		0.0882	0.058	0.0584	0.0583
800		0.0784			
900		0.0707			

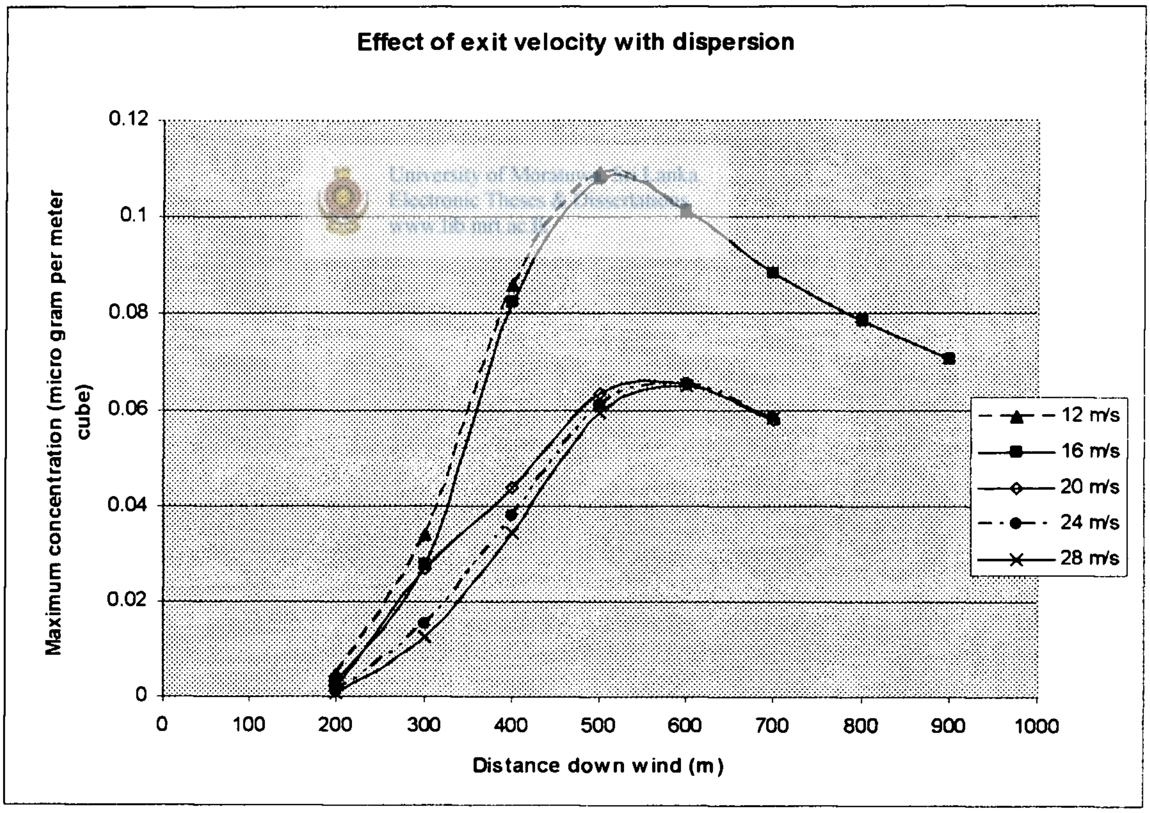


Figure 4.4: Effect of plume exit velocity on dispersion

Even though the dispersion pattern is almost the same with all plume exit velocities there are clear differences between the magnitude of concentrations. This type of analysis is very much useful in deciding the optimum exit velocity of the plume to have minimum impact on the environment or to have pollutant concentrations below the stipulated values.

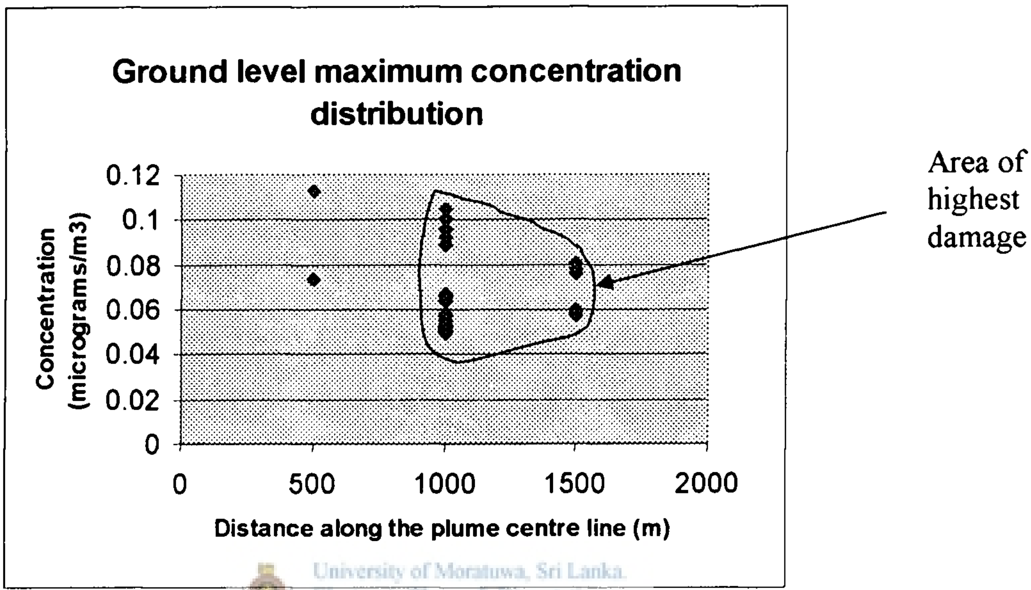


Figure 4.5: Maximum concentration points at ground level for an emission from a stack height 50m and wind velocity 20m/s

The Figure 4.5 gives the maximum concentration points distribution in the downwind direction at the ground level with all the other parameters remaining the same as in Table 4.1 except the stack height. A stack height of 50m was considered in this case. It is clear from the graph that the area of highest impact falls in the range 1000m - 1500m. However, these concentration values are much higher than those estimated for a stack height of 80m. Therefore it can be seen that the stack height is one of the critical factors in stack designing to prevent adverse environmental impacts due to pollutant dispersion.

Table 4.3: Emission Data for the Hypothetical Constituent in the Stack Emission

Parameter	***Value***
Height of the stack (m)	50
Diameter (m)	1.4
Exit temperature (^{0}C)	120
Exit velocity of the plume (m/s)	25
Emission rate of the constituent (kg/hr)	0.0125

The Table 4.3 shows the stack emission data for the same hypothetical constituent considered in earlier cases in this study, with a different stack height and exit plume velocity. The results determined by applying data in Table 4.3 in the AUSPLUME model are discussed below.

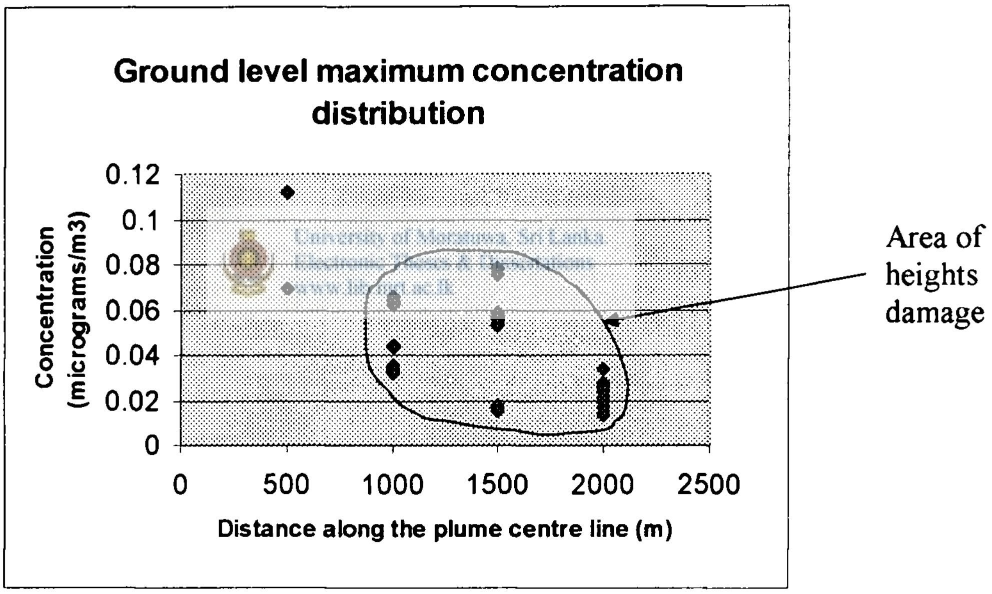


Figure 4.6: Ground Level Maximum Concentration for an Emission from a Stack Height 50m and Wind Velocity 25m/s

The Figure 4.6 shows the maximum concentration distribution related to the parameters given in Table 4.3. The maximum concentration points have reached a distance up to 2000m which is 500m further from the case shown in Figure 4.5. This could be because the exit velocity of the plume being higher than the case given in Figure 4.5. The concentrations also show higher values and this could be due to the shorter stack height considered in Table 4.3.

It can be also checked whether there are any type of sensitive areas such as archeologically valuable sites, high bio diversity or populated areas are located in the area of highest effect.

If these types of areas are situated within the area of highest damage, necessary remedial measures have to be proposed to mitigate them through the EIA.

4.2 Application of AUSPLUME to Holcim stacks

In Puttalam Holcim cement plant there are two stacks of same size located closely. Therefore the two of them can be considered as a single point source. Stack 1 and 2 are connected to kiln 1 and 2 respectively. Both kilns are supposed to run throughout 24 hrs unless otherwise there are operational problems.

The analysis here is done in two ways.

I. Dispersion of the plume for Stack 1 before and after the installation of filter bags assuming the operation of kiln 1 during the considered time period. Stack 1 was selected in this analysis because of the availability of data during the two periods considered.

II. Total dispersion from both stacks assuming them to be a single point source.

The constituents in the emissions from the stack selected for the analysis are particulate matter, CO_2, SO_2 and NO_2. A sample emission data file is given in Annexure 4. The particulate matter is important to consider since the surrounding area can be observed to be polluted due to them. The other three gaseous emissions are important since they contribute to the green house effect as well as the acid rain. These two scenarios may not be directly affecting Sri Lanka but these are global environmental problems.

Approach 1: Dispersion of the plume for Stack 1

Emission data for Stack 1 obtained from Holcim cement plant emission data records in years 2004 and 2005 are given in table 4.4 below.

Table 4.4: Emission data for Stack 1

Parameter	2004		2005	
Air flow (m^3/min)	3110.79	September	2529.31	September
Stack temperature (^0C)	138.97	September	145.14	January
Particulate matter (mg/ m^3) in the exit plume	894.85	September	39.76	March
CO_2 (% volume) in the exit plume	10.01	September	12.07	September
NO_2 (mg/ m^3) in the exit plume	18.89	September	23.73	September
SO_2 (mg/ m^3) in the exit plume	0.99	September	9.86	September

Due to the non availability of data the following assumptions were made in the analysis.

- The stack temperature during September 2005 are similar to that of January 2005
- The particulate matter concentration in the exit plume during September 2005 are similar to that of March 2005

The above assumptions can be made because the temperature and air flow are operational parameters related to the kiln and they would be optimum values for efficient operation.

a. Dispersion of particulate matter

The particulate matter is considered to be PM10 which are not gravitationally settling.

Table 4.5: Maximum ground level concentrations of particulate matter calculated using ASPLUME

Distance in the downwind direction (m)	Max concentration (microg/m^3)- Sep 2004	Max concentration (microg/m^3)- Sep 2005
1000	809	34.5
1500	1360	51.7
2000	1410	51.6
2500	1270	46.1
3000	1110	40.2
3500	974	35.2
4000	865	31.3
4500	779	28.1
5000	709	

The maximum concentration distribution determined using AUSPLUME is graphically given below.

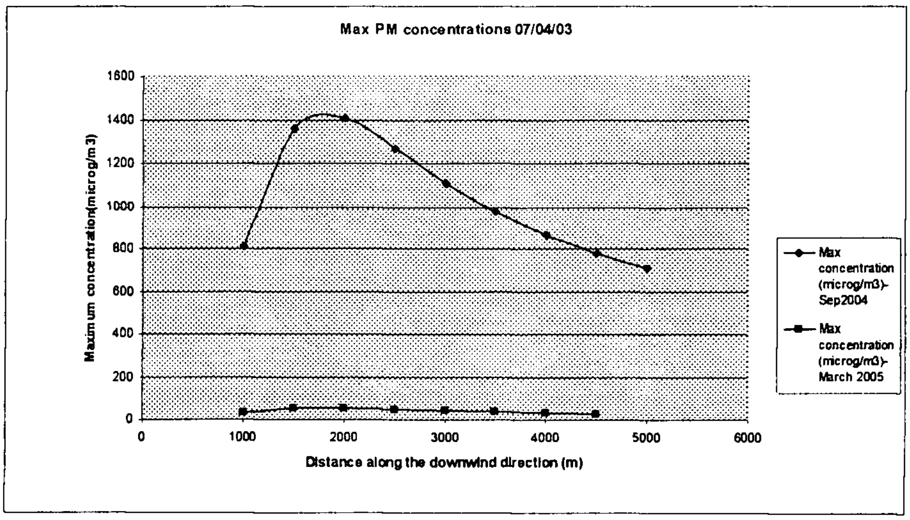


Figure 4.7: Distribution of maximum ground level concentrations of particulate matter

During September 2004 there was an electrostatic precipitator which was used for the removal of dust particles. In March 2005 a bag house was introduced for particulate removal due to the non performance of the electrostatic precipitator. The drastic reduction of particulate matter was due to the installation of the bag house.

According to the Holcim officials during the period of 2004 the monitoring equipment of the stack emissions was measuring the heavy dust as well. The reading of 894.85 mg/m^3 consists of PM10 as well as larger particles which settle gravitationally.

In calculating the dispersion the above factor was neglected and it was assumed that the entire quantity is PM10 which is not gravitationally settling. Therefore the dispersion values contain a certain percentage of inaccuracy.

b. Dispersion of CO_2

The maximum concentration of CO_2 at selected points along the plume centre line calculated for September 2004 and September 2005 by AUSPLUME is given in the following table.

Table 4.6: Maximum CO_2 concentrations

Location (m)	Max concentration (µg/m^3)-Sep2004	Max concentration (µg/m^3)- Sept 2005
1000	697	765
1500	1170	1140
2000	1210	1140
2500	1090	1020
3000	956	890
3500	838	780
4000	745	693
4500	670	624
5000	610	601

The above dispersion is graphically shown below.

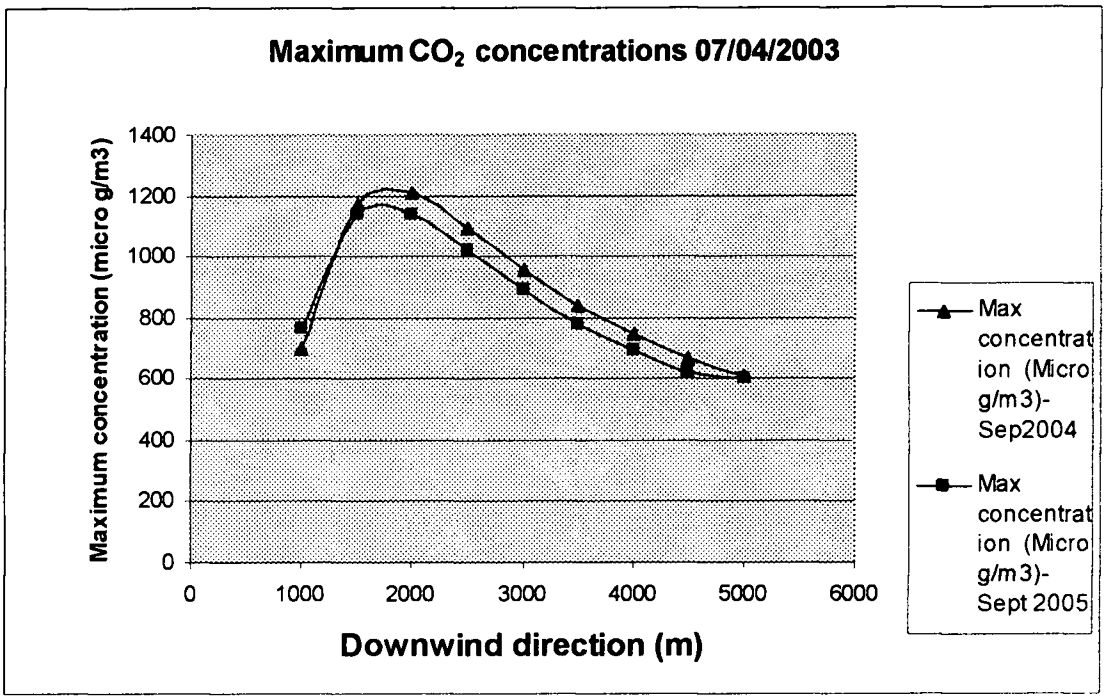


Figure 4.8: Distribution of maximum CO_2 concentrations

The dispersion curves are more or less the same other than slight variations in the values. This is expected since the bag house was the only major change in the cement production process during the period of analysis and it has no effect on the variation in CO_2 emission.

c. Dispersion of NO_2

The maximum concentration of NO_2 at selected points along the plume centre line calculated for September 2004 and September 2005 by AUSPLUME is given in the following table.

Table 4.7: Maximum ground level concentrations of NO_2

Location (m)	Max concentration ($\mu g/m^3$)-Sep2004	Max concentration ($\mu g/m^3$)- Sept 2005
1000	17.1	20.6
1500	28.8	30.8
2000	29.7	30.8
2500	26.8	27.5
3000	23.4	24.0
3500	20.6	21.0
4000	18.3	18.7
4500	16.4	16.8
5000	15.0	16.2

The dispersion is graphically shown below.

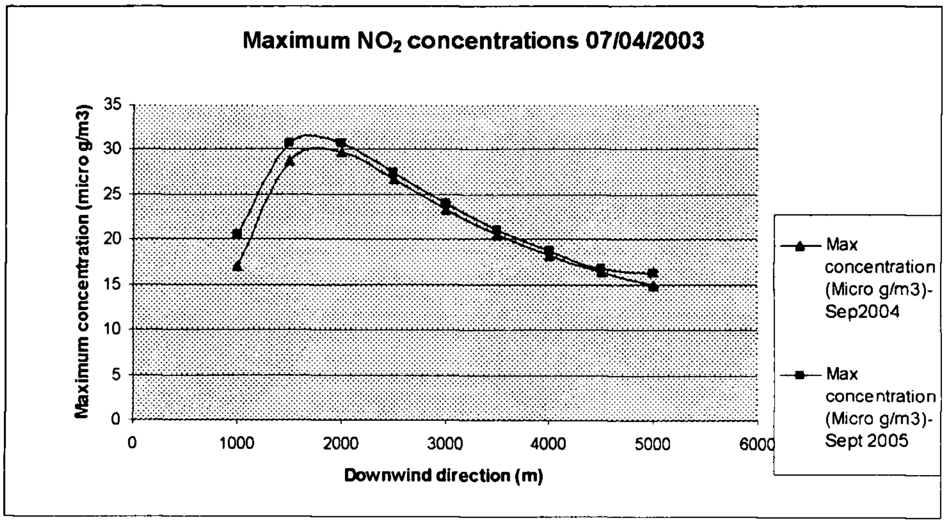


Figure 4.9: Maximum NO_2 concentration distribution

The dispersion curves are more or less the same. Again this is expected since the bag house has no effect on the combustion process and therefore the NO_2 emission.

d. Dispersion of SO_2

The maximum concentration of SO_2 at selected points along the plume centre line calculated for September 2004 and September 2005 by AUSPLUME is given in the following table.

Table 4.8: Maximum ground level SO_2 concentrations

Location (m)	Max concentration (μ g/m^3)-Sep2004	Max concentration (μg/m^3)- Sept 2005
1000	0.90	8.56
1500	1.51	12.80
2000	1.56	12.80
2500	1.41	11.40
3000	1.23	9.96
3500	1.08	8.73
4000	0.96	7.75
4500	0.86	6.98
5000	0.78	

The dispersion is graphically shown below.

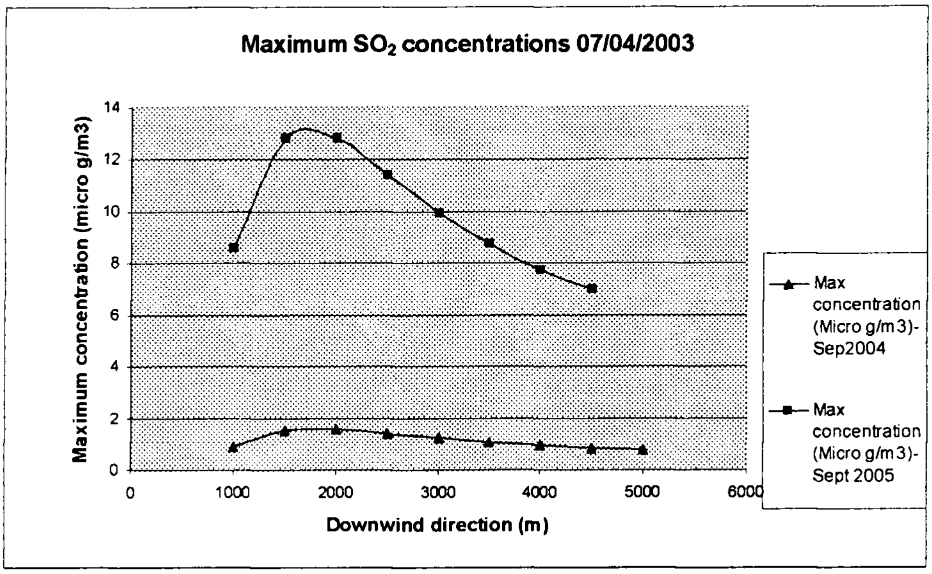


Figure 4.10: Distribution of maximum SO_2 concentrations

The dispersion values have increased in 2005 September, however the levels are well below the stipulated value 200 μg/m^3. Since the bag house has no effect on SO_2 emission this type of variation is not expected. The reasons for the variation can either be the quality of fuel of the quality of raw materials, from which the fuel quality has a greater impact.

From all the above results the following remarks can be made.

- The maximum concentrations occur at a distance between 1500m to 2000m.
- The maximum concentrations occurred on 07/04/2003. The meteorological data on that day are shown in table 4.9.

Table 4.9: Variation of meteorological conditions on 07/ 04/ 2003

Hour	Ambient temperature (^0C)	Wind speed (m/S)	Wind direction (degrees)
1	29	3.0	45
2	29	2.4	45
3	29	1.9	45
4	29	1.8	45
5	29	1.8	45
6	29	1.8	90
7	29	1.4	90
8	29	1.1	90
9	29	0.7	45
10	29	1.7	45
11	29	2.6	45
12	29	3.6	270
13	29	3.9	270
14	29	4.2	270
15	29	4.5	270
16	29	3.7	270
17	29	2.9	270
18	29	2.1	270
19	29	1.6	270
20	29	1.1	270
21	29	0.6	270
22	29	0.7	270
23	29	0.8	270
24	29	0.9	45

The hour highlighted shows the time at which the maximum ground level concentrations occur.

Approach 2: Dispersion of the plume from Stack 1 and Stack 2 assuming them both together be a single point source

Assuming the data for Stack 1 during January 2004 is similar to that in September 2004 following data for the equivalent stack were obtained. It was also assumed that the equivalent stack has emissions equivalent to the addition of the two individual stacks. A specimen calculation for this equivalent stack emission is given in Annexure 5.

Table 4.10: Emission data for the Equivalent stack

Parameter	Stack 1	Stack 2	Equivalent stack
Air flow (m^3/min)	3110.79	3110.79	6221.58
Stack temperature (^0C)	138.97	135.36	137.16
Particulate matter (mg/ m^3)	894.85	863.52	1758.37
CO_2 (% volume)	10.01	14.42	12.22
NO_2 (mg/ m^3)	18.89	31.92	50.81
SO_2 (mg/ m^3)	0.99	17.16	18.15

Diameter of each stack is 1.4m and therefore the diameter of the equivalent stack is taken as 1.98 m. This value was taken by taking the addition of the areas of the stack openings in the two stacks is similar to the exit area of the equivalent stack.

As previously done, the AUSPLUME was used to calculate the ground level maximum concentrations at selected locations and the values were compared with the same values of Stack 1 when individually operated.

a. Dispersion of particulate matter

The maximum ground level concentrations are given below.

Table 4.11: Maximum ground level particulate matter concentrations

Downwind distance (m)	Max concentration (µg/m^3)- Sep2004	Max concentration (µg/m^3)- September 2004 Equivalent stack
1000	809	1210.0
1500	1360	2650.0
2000	1410	3060.0
2500	1270	2920.0
3000	1110	2630.0
3500	974	2350.0
4000	865	2110.0
4500	779	1930.0
5000	709	1800.0

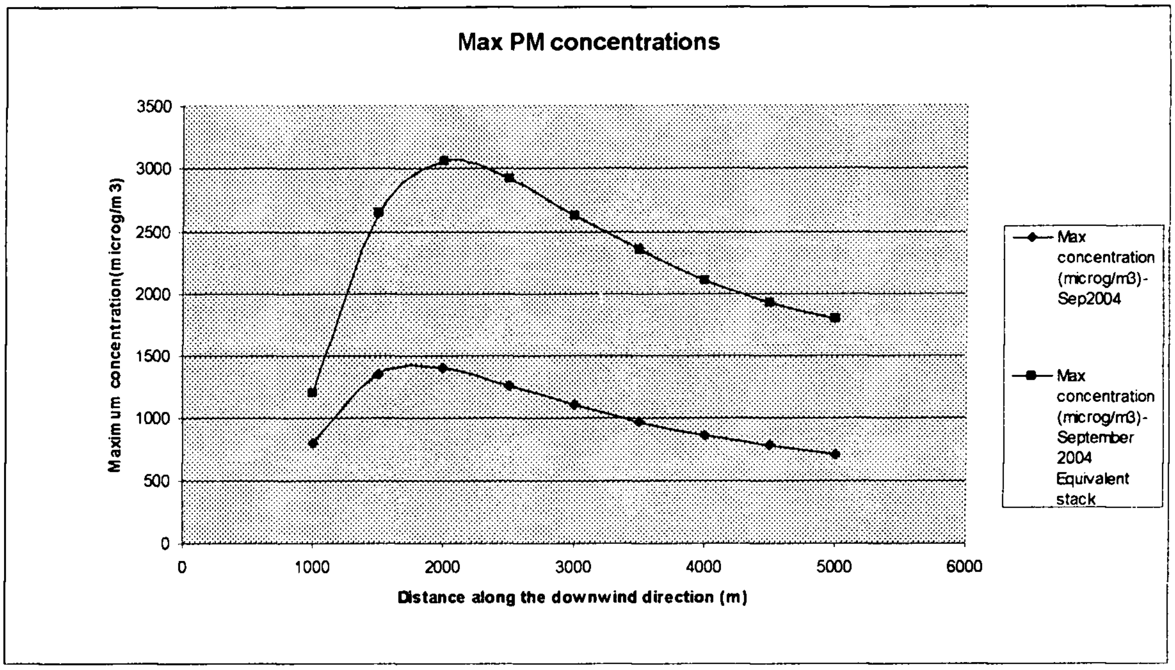


Figure 4.11: Distribution of maximum ground level concentrations of particulate matter

Combine effect of the two stacks is higher than a single stack. However maximum concentrations for the equivalent stack occur roughly 500m further down wind.

b. Dispersion of NO_2

Maximum ground level concentrations of NO_2 estimated using the ASPLUME are tabulated below (Table 4.12) and the graphical distribution (Figure 4.12) is followed.

Table 4.12: Maximum ground level NO_2 concentrations

Downwind distance (m)	Max concentration ($\mu g/m^3$)-Sep2004 (07/04/2003)	Max concentration ($\mu g/m^3$)- Sept 2004 Equivalent stack (19/03/03)
1000	17.1	35.0
1500	28.8	76.5
2000	29.7	88.6
2500	26.8	84.4
3000	23.4	76.0
3500	20.6	67.8
4000	18.3	61.0
4500	16.4	55.7
5000	15.0	

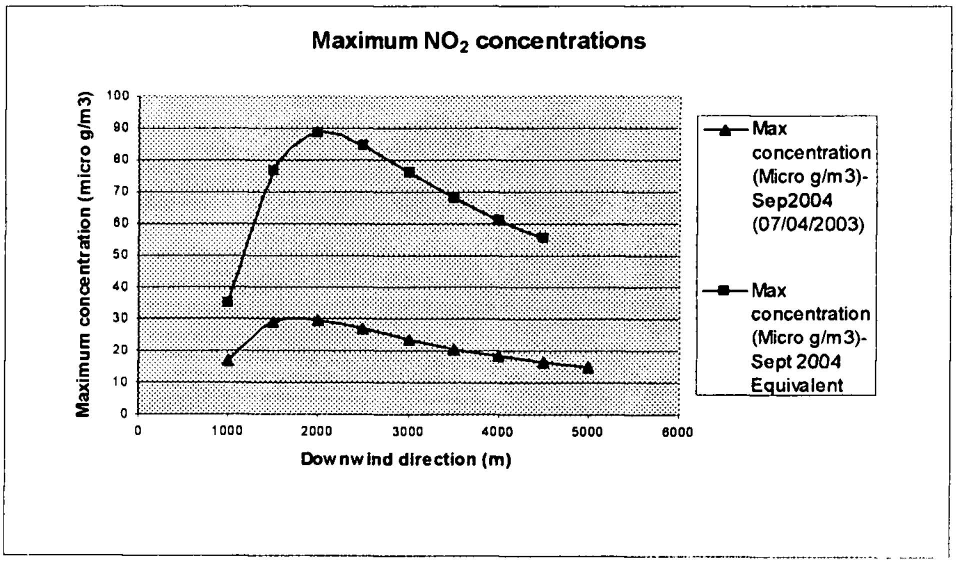


Figure 4.12: Distribution of maximum ground level concentrations of NO_2

The combine effect is higher than a single stack as it is expected. Again, maximum concentrations for the equivalent stack occur roughly 500m further down wind.

c. Dispersion of SO_2

Maximum ground level concentrations of SO_2 modelled using AUSPLUME are tabulated below (table 4.13) and the graphical distribution is followed (figure 4.13).

Table 4.13: Maximum ground level SO_2 concentrations

Downwind distance (m)	Max concentration ($\mu g/m^3$)-Sep2004	Max concentration ($\mu g/m^3$)- Sept 2004 Equivalent stack
1000	0.90	12.50
1500	1.51	27.30
2000	1.56	31.60
2500	1.41	30.20
3000	1.23	27.10
3500	1.08	24.20
4000	0.96	21.80
4500	0.86	19.90
5000	0.78	18.50

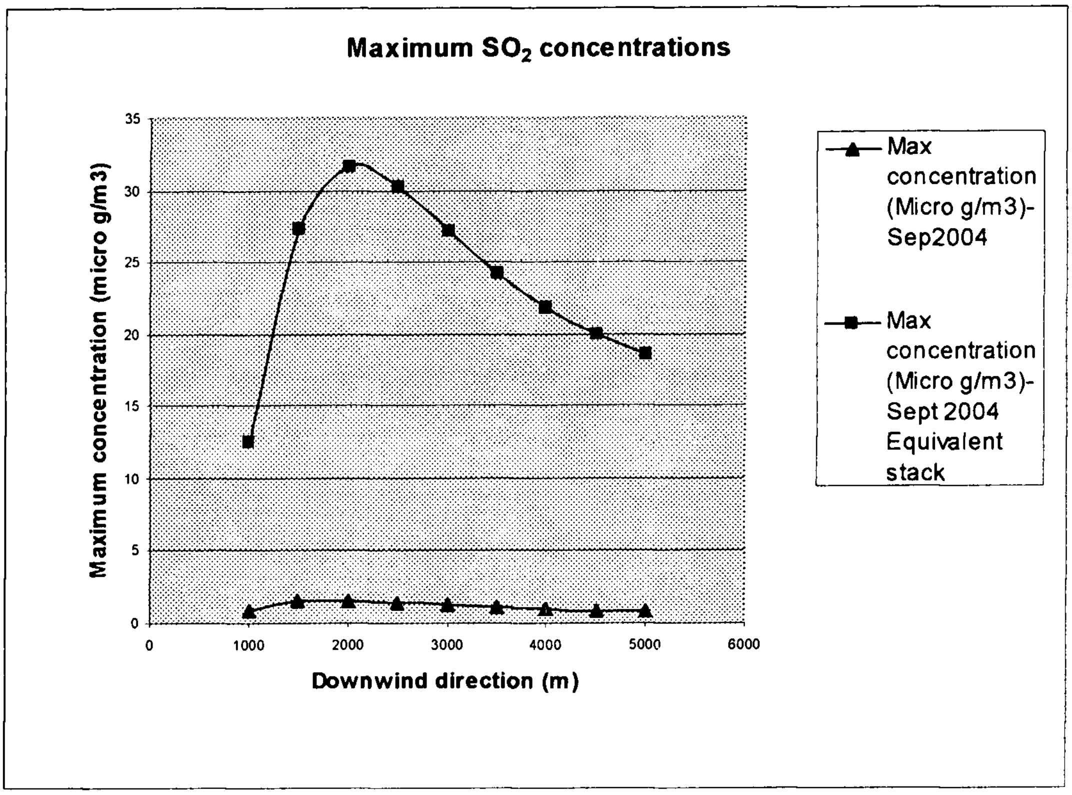


Figure 4.13: Distribution of maximum ground level concentrations of SO_2

Effect from the equivalent stack is higher than the effect from a single stack, as expected.

d. Dispersion of CO_2

Maximum ground level concentrations of CO_2 are tabulated below (Table 4.14) and the graphical distribution (Figure 4.14) is followed.

Table 4.14: Maximum ground level CO_2 concentrations

Downwind distance (m)	Max concentration (μg/m³)-Sept 2004	Max concentration (μg/m³)- Sept 2004 Equivalent stack
1000	697	1560
1500	1170	3410
2000	1210	3950
2500	1090	3760
3000	956	3390
3500	838	3020
4000	745	2720
4500	670	2480
5000	610	2310

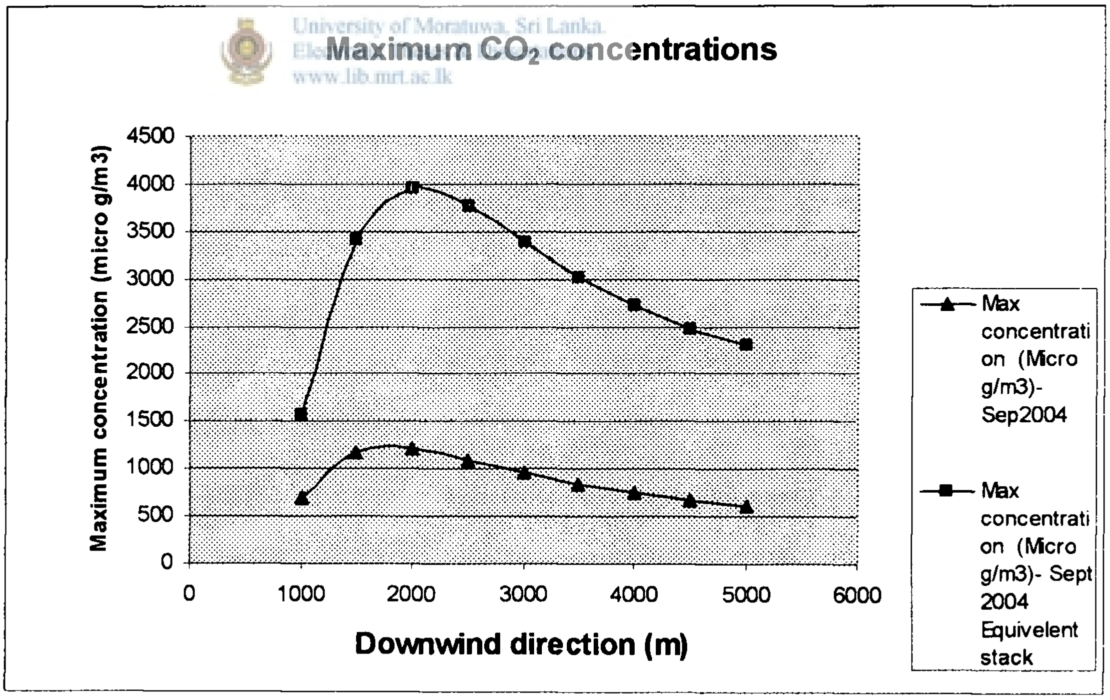


Figure 4.14: Distribution of maximum ground level concentrations of CO_2

It was observed from the results of AUSPLUME that the maximum concentration of the Equivalent stack occurred on 19/03/03. The meteorological data for that day are,

Table 4.15: Variation of meteorological conditions on 19/ 03/ 03

Hour	Ambient temperature (^{0}C)	Wind speed (m/S)	Wind direction (degrees)
1	28	0.00	0
2	28	0.00	0
3	28	0.00	0
4	28	0.00	0
5	28	0.00	0
6	28	0.00	0
7	28	0.00	0
8	28	0.00	0
9	28	0.72	68
10	28	0.48	68
11	28	0.24	68
12	28	0.00	0
13	28	0.00	0
14	28	0.00	0
15	28	4.02	270
16	28	4.14	270
17	28	4.26	270
18	28	4.38	270
19	28	3.10	270
20	28	1.82	270
21	28	0.54	315
22	28	0.36	315
23	28	0.18	315
24	28	0.00	0

CHAPTER 5 : RESULTS AND DISCUSSSION

5.1 Applicability of AUSPLUME in Environmental Impact Assessment- a hypothetical case study

The results obtained in the analysis of the hypothetical plant conducted in Chapter 3.1 can be summarized in the Table 5.1 as follows.

Table 5.1: Pollutant Dispersion Results using AUSPLUME

Figure No.	Height of the stack (m)	Diameter (m)	Exit temperature (°C)	Exit velocity of the plume (m/s)	Emission rate of the constituent (kg/hr)	Concentration Value estimated elevation (m)	Range of maximum 100 concentration distribution (m)	Maximum Concentration (μg/m³)	Minimun concentrati (μg/m³)
1	**80**	1.4	120	20	0.0125	0	1000-2000	0.0634	0.0077:
2	**80**	1.4	120	20	0.0125	30	1000-2000	0.0651	0.0102
3	**80**	1.4	120	25	0.0125	0	1000-2000	0.0628	0.0068
4	**50**	1.4	120	20	0.0125	0	1000-1500	**0.113**	0.0497
5	**50**	1.4	120	25	0.0125	0	1000-2000	**0.112**	0.0131

According to the above results it is clear that for a shorter stack height the downwind ground level concentrations are also very high. Even though the maximum 100 concentrations are used in this analysis, it can be further predicted that even the concentrations below the 100th one can be relatively higher. This indicates that all the concentration values above the government stipulated concentration of the constituent must be considered in deciding the extent of the buffer zone. Air pollution control measures are also necessary in this case.

In the process of EIA, depending on the predicted impacts the mitigation measures can be prioritized. Therefore the estimations done using the model must be fairly accurate because the measures to mitigate will cost money. However, these predictions carry a certain amount of inaccuracy. The coefficients or constants used in the AUSPLUME model which have been validated for some other country may carry a certain percentage of inaccuracy when applying it in Sri Lanka. The estimation of coefficients suitable for this country should be looked at in a further study.

Sri Lanka as a developing country has not paid much attention towards the environmental sustainability. The people are not very concerned about the importance of protecting the environment or the adverse effects due to the unsustainable use of the environmental resources. However, the government of Sri Lanka has paid a certain amount of attention on these issues specially the industrialists are being made responsible for what ever the actions they take which can cause adverse environmental impacts. Sri Lanka has not faced air pollution of serious magnitude and it is not among five key environmental issues of the country (Ministry of environment and natural resources, 2000). This may be because of the location of the country. It is an island in the Indian Ocean and it has continuous sea breeze, monsoon and inter monsoon winds which keep the air always in motion. However if uncontrolled emissions increase with the increased number of industries as well as development projects we will have to face air pollution problems in the near future.

Hence it is very much important to construct the industries with preventive measures for the mitigation of air pollution problems. The industrial stack is very critical under this aspect and therefore it is recommended to use a model like AUSPLUME. When compared with the other models which have been used for EIA purposes AUSPLUME has a great amount of flexibility and also it has proven results worldwide in the process of EIA.

5.2 Application of AUSPLUME to Puttlam Holcim stacks

5.2.1 Comparison of the predicted values with standards

According to the Central Environmental Authority officials Sri Lanka still does not have emission standards. Available ambient air quality standards are given below. A copy of the Gazette is given in Annexure 6. These were also developed by considering the health impacts. The value for PM_{10} used by the CEA is the standard recommended by USEPA.

Table 5.2: Ambient air quality standards in Sri Lanka

Substance	Time weighted average	Averaging time
NO_2	250 µg/ m^3	1 hr
PM	300 µg/ m^3	24 hr
SO_2	200 µg/ m^3	1 hr

For comparison the European standards are given below. These are guideline values for individual substances based on effects other than cancer or odour or annoyance. Numerical guideline values are not to be regarded as separating the acceptable from the unacceptable, but rather as indications. They are proposed in order to help avoid major discrepancies in reaching the goal of effective protection against recognized hazards for human health and the environment.

Table 5.3: European standard guideline values

Substance	Time weighted average	Averaging time
NO_2	200 µg/ m^3	1 hr
PM	Dose- response	
SO_2	500 µg/ m^3	10 mins

Given below are the maximum concentrations of NO_2, SO_2 and particulate matter from the equivalent stack for the emission data during 2004 September and September 2005 for the stack 1 as predicted by AUSPLUME.

Table 5.4: Maximum time weighted average values of NO_2, SO_2 and particulate matter

Downwind distance (m)	Maximum concentration (µg/ m^3)					
	NO_2		SO_2		Particulate Matter	
	Equivalent stack 2004	Equivalent stack 2005	Equivalent stack 2004	Equivalent stack 2005	Equivalent stack 2004	Equivalent stack 2005
500	6.48	***358***	2.3	145	30	24
1000	141	***251***	50	105	***403***	30
1500	***308***	196	110	81	***883***	45
2000	***355***	189	127	83	***1020***	45
2500	***337***	174	120	72	***974***	41
3000	***301***	151	107	63	***876***	37
3500	***266***	131	94	55	***782***	33
4000	237	120	84	51	***704***	30
4500	213	105	76	45	***643***	28
5000	194	95	69	40	***599***	26

According to the above results it is clear that before the installation of the bag house (2004) the dust levels were higher than the stipulated value which is 300 µg/ m^3.

From the analysis done in Chapter 4, Section 4.2 it seems that the highest ambient concentrations occur between 1- 2 km. This area can be identified as the most suitable area for monitoring the ambient dispersions.

5.2.2 Comparison of results of AUSPLUME with field measurements

Ambient particulate matter (PM_{10}) measurements have been done by the company during the past at different locations are given below.

Locations

1. Air force Camp - 2 km from the plant South Western
2. School - 1.5 km from the plant - South Eastern
3. Company Guest House - 3.5 km from the plant Easter side
4. Crusher 2 - Inside the plant - North Western Corner

Table 5.5: Measured ambient PM_{10} concentrations at different locations

Month of measurement	Location 1 ($\mu g/m^3$)	Location 2 ($\mu g/m^3$)	Location 3 ($\mu g/m^3$)	Location 4 ($\mu g/m^3$)
April 2002	30	1270	30	-
May 2004	40	40	40	-
June 2004	40	40	520	-
August 2004	20	20	360	-
September 2004	20	20	260	-
October 2004	40	40	40	-
May 2005	40	1	-	-
December 2005	10	20	20	40

The estimated and real values during the operation of both stacks are plotted in the following figures for comparison.

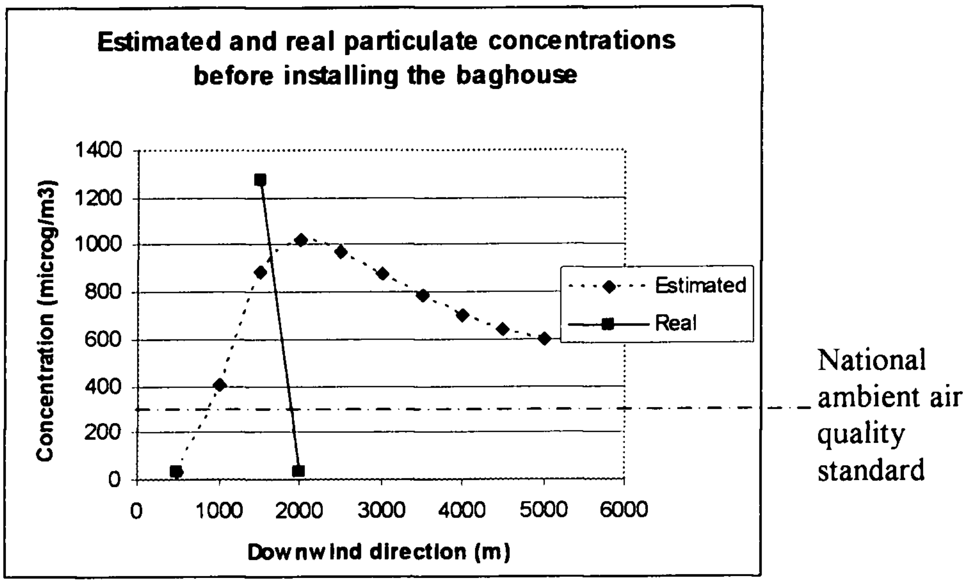


Figure 5.1: Estimated and real particulate concentrations before installing the baghouse

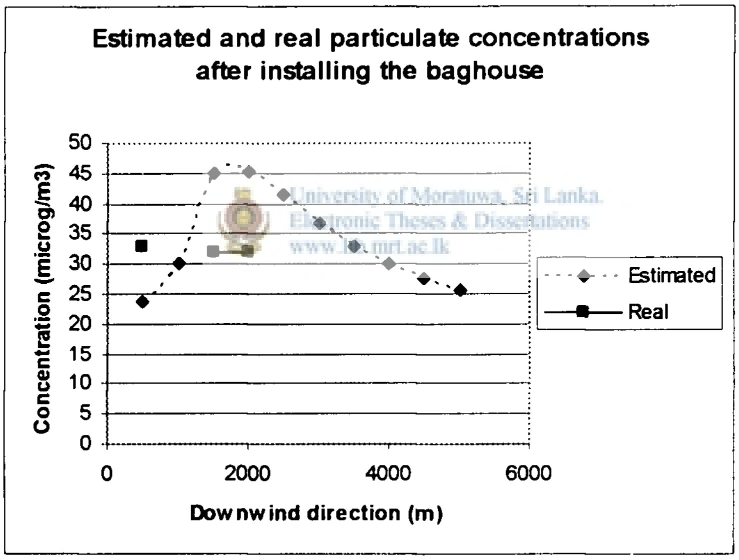


Figure 5.2: Estimated and real particulate concentrations after installing the baghouse

The above graphs show that the real and estimated values are not exactly the same. This can be due to several reasons, like,

- The differences in the directions. Measurements may have not been done in the downwind direction.
- Inaccuracies in the predicted values due to insufficient meteorological data

5.2.3 Comparison of results of AUSPLUME and SCREEN 3 models

A comparison of predicted dispersion values from AUSPLUME and SCREEN 3 model is given below. SCREEN3 model has been used for several EIA studies in Sri Lanka. The output from the SCREEN3 run is given in Annexure 9 which consists of input data as well.

Table 5.6: Downwind peak concentrations of particulate matter for a single stack using data observed after the installation of the bag house

Downwind distance (m)	AUSPLUME (μg/m^3)	SCREEN3 (μg/m^3)
500	12	335
1000	15	705
1500	22.5	511
2000	22.5	456
2500	20.5	410
3000	18.5	379
3500	16.5	361
4000	15	345
4500	14	323
5000	13	307

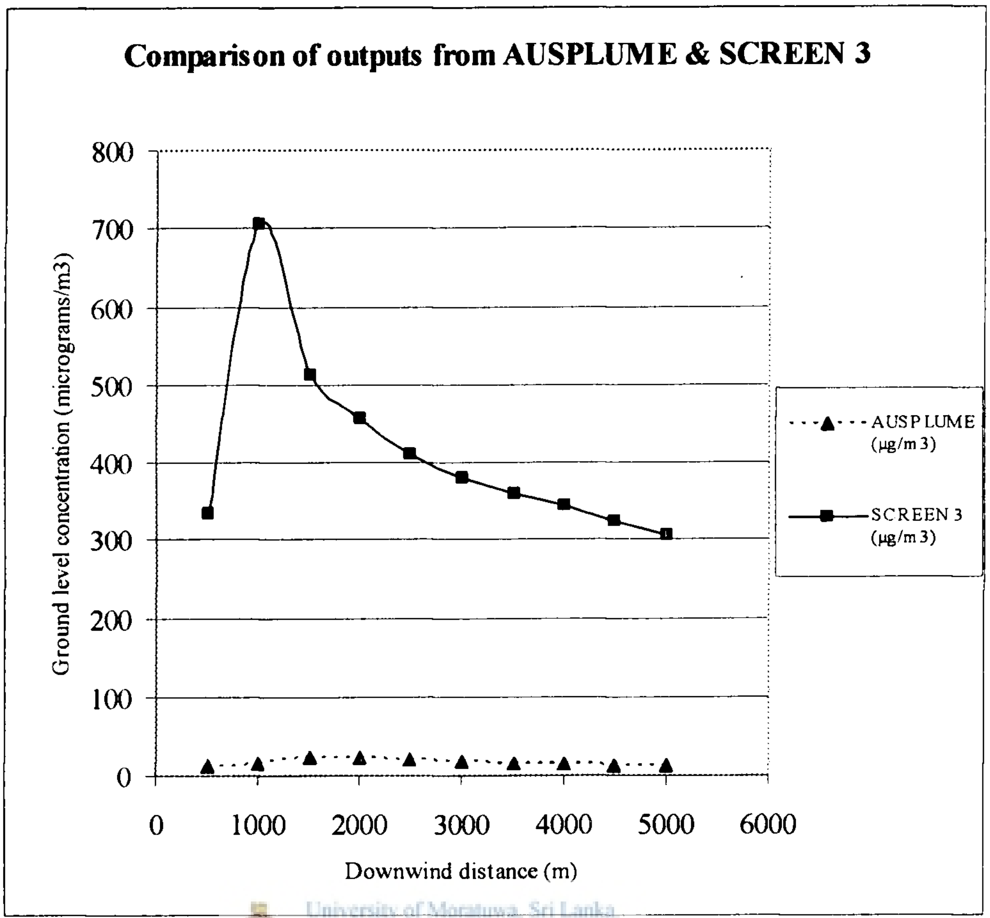


Figure 5.3: Predicted ground level; concentration of particulate matter using AUSPLUME and SCREEN 3

The predicted values from the two models are not the same. However both show an increase in values initially and a decrease later. Values predicted by SCREEN3 are much higher than those from AUSPLUME. AUSPLUME requires hourly meteorological values for 365 days to predict the peak dispersion values. SCREEN3 only requires ambient temperature data other than the source data. SCREEN3 gives the maximum concentrations at the worst weather conditions. Therefore it is possible to get higher concentrations when SCREEN3 is used since it predicts the worst possible situation.

CHAPTER 6: CONCLUSIONS

The following conclusions can be made using the analysis done in Chapter 4.

- AUSPLUME is recommended for use in the EIA for industrial stacks in Sri Lanka;
    - it has a range of options and many combinations of parameters can be analyased
    - a strong meteorological data file consisting hourly data for 365 days is required and therefore the accuracy of the results should be higher than with other model (provided the meteorological data are correct)
    - it has proven results worldwide

- New dust abatement system at Puttlam Holcim plant operates quite satisfactorily;
    - After the installation of the bag house the dispersion due to the equivalent stack is well below the stipulated value
    - Field measurement values are also much below the stipulated value
    - The estimated and measured values are different but same order of magnitude

According to the analysis, the most suitable distance for monitoring the ambient dispersions is in the range of 1.5 – 2.5 km downwind from the plant.

CHAPTER 7 : OPPORTUNITIES AVAILABLE FOR FUTURE WORK

- More field measurements have to be done in order to determine the accuracy of AUSPLUME to Sri Lankan conditions; further validation, and sensitivity analysis is also important.

- Holcim can establish emission monitoring stations in the major wind directions for frequent measurement and can do occasional measurements at the already selected areas. These monitoring stations can be established in the distance of 1.5 km- 2.5 km from the stack, where highest concentrations occur. (Annexure 8)

- If there is a possibility of installing a continuous meteorological data monitoring station at a certain area coupled with the AUSPLUME software it is possible to monitor the emission dispersion through out. However this type of a monitoring system will be necessary for an area where
    - the emissions are associated with proven health effects in the people living in the area
    - the emissions are significant
    - the emissions are considerably changing with rapid industrial development
    - the emissions may not be significant or not even prove to be harmful but causing any type of pollution

The benefit of having a continuous modeling system should be justifiable with the cost of installing and maintaining such a system.

- Specifically in Puttlam area these results can be compared in future if a thermal power plant is constructed in the vicinity.

- To find out the effect of dust on the human health, it is better to interview the people living in the area close to the cement plant as well as the employees of the plant.

- Several assumptions were made in the preparation of the meteorological data file and it is required to find the effects due to these assumptions on the accuracy and reliability of the results.

- More future work will involve in studying the dispersion under different conditions to the conditions considered in Tables 4.1 and 4.2 with AUSPLUME. As for an example effects due to different stack heights, diameters, locations and exit flow rate can be compared by using the earlier described results. Effects of the high rise buildings can be analyzed by considering different stack positions. Cumulative effects of the possible future construction, effects due to increase in road traffic can also be analyzed.

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Annexure 1: Sample meteorological file

```
Palavi weather station 20003
03010101 25  0.6 45  D 200
03010102 25  0.6 45  D 200
03010103 25  0.6 45  D 200
03010104 25  0.4 45  D 200
03010105 25  0.2 45  D 200
03010106 25  0.0 0  A 200
03010107 25  0.0 0  A 200
03010108 25  0.0 0  A 200
03010109 25  0.5 45  A 300
03010110 25  0.5 45  A 300
03010111 25  0.5 45  A 300
03010112 25  0.5 68  A 300
03010113 25  1.3 68  A 1000
03010114 25  2.0 68  A 1300
03010115 25  2.7 338 B 1400
03010116 25  1.9 338 A 1300
03010117 25  1.2 338 A 600
03010118 25  0.5 338 A 300
03010119 25  0.5 338 D 200
03010120 25  0.5 338 D 200
03010121 25  0.5 0  A 300
03010122 25  0.5 0  A 300
03010123 25  0.5 0  A 300
03010124 25  0.5 45  D 200
03010201 25  1.2 45  D 400
03010202 25  1.9 45  D 800
03010203 25  2.7 45  F 5000
03010204 25  1.8 45  D 800
03010205 25  0.9 45  D 400
03010206 25  0.0 0  A 400
03010207 25  0.0 0  A 400
03010208 25  0.0 0  A 400
03010209 25  0.5 68  A 300
03010210 25  2.1 68  B 1100
03010211 25  3.8 68  C 1800
03010212 25  5.5 45  D 2600
03010213 25  4.2 45  C 1800
03010214 25  2.8 45  B 1700
03010215 25  1.4 45  A 600
03010216 25  1.0 45  A 600
03010217 25  0.5 45  A 300
03010218 25  0.0 0  A 300
03010219 25  0.0 0  A 500
03010220 25  0.0 0  A 500
03010221 25  1.3 45  D 600
03010222 25  1.4 45  D 500
03010223 25  1.4 45  D 500
03010224 25  1.4 45  D 500
03010301 25  1.9 45  D 800
03010302 25  2.4 45  D 1100
03010303 25  3.0 45  D 1300
```

Annexure 2: Dispersion models used in the EIA processes

No.	Proposed project	EIA publicized time	EIA carried out by	Dispersion model used	Purpose
1	Sapugaskanda BOO (Build-Own-Operate) power station	December 1993	Ewbank Preece Ltd., Brighton	ISCST ISCLT	* Peak 01-hour dispersion values at ground level * Downwind direction distance of the maximum concentration for all stability classes *Annual maximum dispersion values/distance
2	Kelanitissa combined-cycle power plant	December 1995	Resources Development Consultants, Sri Lanka	USEPA Screen 1.1	For the analysis of worst possible environmental condition
3	Hambantota integrated petroleum refinery and power plant	January 1996	Regional Cooperative Petroleum Refinery Inc., Hong Kong	USEPA Screen	For the analysis of impact of emission, covering full range of meteorological data for all stability classes to obtain the maximum concentration
4	Sapugaskanda power station extension project	April 1996	Mott Ewbank Preece, UK	USEPA Screen 3 ISCLT II	Short-term (1hr, 8hr, 24hr) dispersion analysis Annual dispersion

5	Kalpitiya coal-fired thermal development project	March 1998	Electrowatt Engineering Ltd.- Switzerland, Pacific Consultants International-Japan, Lanka Hydraulics Engineering Consultants Ltd.-SL	ISC 2	Analyzing the ambient air dispersion (This model is the most versatile USEPA model for coal-fired power plants
6	Port of Colombo barge-mounted thermal power plant	March 1998	ERM, Sri Lanka	USEPA Screen	Peak concentrations along downwind direction at 1m/s and 3m/s for all stability classes
7	Kelanitissa 163MW combined-cycle gas turbine	August 1999	Environmental Resource Management (ERM), Sri Lanka	ISCST	* For the prediction of short-term and annual (mean) maximum concentrations for various stack heights * For the analysis of existing and future ground level concentrations in the area
8	20MW diesel power plant at Horana export processing zone	November 2001	ERM, Sri Lanka	USEPA Screen 3	Analyzing maximum concentrations in the downwind direction for all stability classes at 1m/s and 3m/s
9	100MW thermal power plant at Puttalam		Team of experts for Heladhanavi Ltd.	USEPA Screen 3	Analyzing maximum concentrations in the downwind direction for all stability classes at 1m/s and 3m/s
10	Lionvert refinery and power plant at Kerawalapitiya	January 2004	Lanka Hydraulics Institute, Sri Lanka	USEPA Screen 3	Analyzing maximum concentrations in the downwind direction for all stability classes at 1m/s and 3m/s for minimum stack height of 40m

Annexure 3: Sample output file

September 2004 - CO_2

Concentration or deposition Concentration
Emission rate units kg/hour
Concentration units microgram/m3
Units conversion factor 2.78E+05
Constant background concentration 0.00E+00
Terrain effects None
Smooth stability class changes? No
Other stability class adjustments ("urban modes") None
Ignore building wake effects? No
Decay coefficient (unless overridden by met. file) 0.000
Anemometer height 10 m
Roughness height at the wind vane site 0.300 m
Averaging time for sigma-theta values 60 min.

DISPERSION CURVES

Horizontal dispersion curves for sources <100m high Sigma-theta
Vertical dispersion curves for sources <100m high Pasquill-Gifford
Horizontal dispersion curves for sources >100m high Briggs Rural
Vertical dispersion curves for sources >100m high Briggs Rural
Enhance horizontal plume spreads for buoyancy? Yes
Enhance vertical plume spreads for buoyancy? Yes
Adjust horizontal P-G formulae for roughness height? Yes
Adjust vertical P-G formulae for roughness height? Yes
Roughness height 0.100m
Adjustment for wind directional shear None

PLUME RISE OPTIONS

Gradual plume rise? Yes
Stack-tip downwash included? Yes
Building downwash algorithm: Schulman-Scire method.
Entrainment coeff. for neutral & stable lapse rates 0.60,0.60
Partial penetration of elevated inversions? No
Disregard temp. gradients in the hourly met. file? No

and in the absence of boundary-layer potential temperature gradients given by the hourly met. file, a value from the following table (in K/m) is used:

Wind Speed Category	Stability Class A	B	C	D	E	F

1	0.000	0.000	0.000	0.000	0.020	0.035
2	0.000	0.000	0.000	0.000	0.020	0.035
3	0.000	0.000	0.000	0.000	0.020	0.035
4	0.000	0.000	0.000	0.000	0.020	0.035
5	0.000	0.000	0.000	0.000	0.020	0.035
6	0.000	0.000	0.000	0.000	0.020	0.035

WIND SPEED CATEGORIES
Boundaries between categories (in m/s) are: 1.54, 3.09, 5.14, 8.23, 10.80

WIND PROFILE EXPONENTS: "Irwin Rural" values (unless overridden by met. file)

AVERAGING TIMES
8 hours

1

September 2004 - CO2

SOURCE CHARACTERISTICS

STACK SOURCE: STACK

X(m)	Y(m)	Ground Elev.	Stack Height	Diameter	Temperature	Speed
0	0	0m	80m	1.40m	139C	33.7m/s

No building wake effects.
(Constant) emission rate = 1.44E+04 kg/hour
No gravitational settling or scavenging.

1

September 2004 - CO2

RECEPTOR LOCATIONS

DISCRETE RECEPTOR LOCATIONS (in metres)

No.	X	Y	ELEVN	HEIGHT	No.	X	Y	ELEVN	HEIGHT
1	500	0	0.0	0.0	6	3000	0	0.0	0.0
2	1000	0	0.0	0.0	7	3500	0	0.0	0.0
3	1500	0	0.0	0.0	8	4000	0	0.0	0.0
4	2000	0	0.0	0.0	9	4500	0	0.0	0.0
5	2500	0	0.0	0.0	10	5000	0	0.0	0.0

METEOROLOGICAL DATA : PALAVI WEATHER STATION 2003

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1 HIGHEST RECORDINGS FOR EACH RECEPTOR (in microgram/m^3)
AVERAGING TIME = 8 HOURS

At the discrete receptors:

1: 8.44E+02 @Hr16,23/04/03 6: 9.56E+02 @Hr16,07/04/03
2: 6.97E+02 @Hr16,07/04/03 7: 8.38E+02 @Hr16,07/04/03
3: 1.17E+03 @Hr16,07/04/03 8: 7.45E+02 @Hr16,07/04/03
4: 1.21E+03 @Hr16,07/04/03 9: 6.70E+02 @Hr16,07/04/03
5: 1.09E+03 @Hr16,07/04/03 10: 6.10E+02 @Hr16,07/04/03

---

1 SECOND-HIGHEST RECORDINGS FOR EACH RECEPTOR (in microgram/m3)
AVERAGING TIME = 8 HOURS

At the discrete receptors:

1: 3.74E+01 @Hr16,07/04/03 6: 6.82E+02 @Hr16,19/03/03
2: 6.13E+02 @Hr16,23/04/03 7: 6.29E+02 @Hr24,29/04/03
3: 8.44E+02 @Hr16,19/03/03 8: 6.23E+02 @Hr24,29/04/03
4: 8.73E+02 @Hr16,19/03/03 9: 6.12E+02 @Hr24,29/04/03
5: 7.83E+02 @Hr16,19/03/03 10: 5.98E+02 @Hr24,29/04/03

1 Peak values for the 100 worst cases (in microgram/m3)
Averaging time = 8 hours

Rank	Value	Time Recorded hour,date	Coordinates (* denotes polar)
1	1.21E+03	16,07/04/03	(2000, 0, 0.0)
2	8.73E+02	16,19/03/03	(2000, 0, 0.0)
3	8.44E+02	16,23/04/03	(500, 0, 0.0)
4	7.90E+02	16,28/03/03	(2000, 0, 0.0)
5	7.74E+02	16,08/04/03	(2000, 0, 0.0)
6	7.13E+02	24,19/03/03	(2000, 0, 0.0)
7	6.52E+02	16,18/06/03	(2000, 0, 0.0)
8	6.29E+02	24,29/04/03	(3500, 0, 0.0)
9	5.78E+02	24,18/04/03	(2000, 0, 0.0)
10	4.64E+02	16,03/03/03	(2000, 0, 0.0)
11	4.53E+02	16,28/06/03	(2000, 0, 0.0)
12	4.53E+02	16,29/06/03	(2000, 0, 0.0)
13	4.52E+02	16,20/03/03	(2000, 0, 0.0)
14	4.42E+02	24,27/04/03	(2000, 0, 0.0)
15	4.37E+02	24,26/04/03	(5000, 0, 0.0)
16	4.23E+02	16,20/06/03	(3500, 0, 0.0)

Annexure 4: Sample emission data for the Puttlam cement plant stack

Device: **MCS100E**

Component: **CO2**

Units: **Vol%**

Interval: **1-hour average**

Time Zone: **Dateline Standard Time**

	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	Max	Avg	Rds
1	11.25	11.12	11.02	10.87	10.87	10.35	10.27	9.64	10.73	11.59	11.92	12.59	12.34	12.70	11.87	11.49	11.44	12.28	11.80	11.99	11.49	10.41	9.84	11.49	12.70	11.31	24
2	9.33	10.22	9.77	9.77	10.39	9.28	10.00	13.00	12.69	10.94	10.97	12.31	11.13	12.15	11.28	8.07 M	0.00 M	6.88 M	12.69	12.37	13.15	13.43	13.68	12.55	13.68	11.48	21
3	12.03	12.10	11.03	10.46	9.57	11.34	11.73	12.19	11.65	4.51	0.08	0.15	0.03	0.12	1.42	3.38	8.46	7.49	8.92	9.46	9.81	10.60	11.16	9.61	12.19	7.80	24
4	9.37	9.59	9.85	10.64	10.12	9.78	9.82	12.18	12.20	12.31	12.26	8.98	9.41	11.63	10.25	10.40	10.56	9.99	10.54	11.19	11.03	11.28	11.34	11.19	12.31	10.66	24
5	11.18	11.22	10.76	10.69	10.86	11.96	12.05	10.24	12.07	11.92	11.66	10.39	10.70	10.85	11.14	11.01	11.09	11.33	11.36	11.29	11.01	11.30	10.54	10.10	12.07	11.11	24
6	10.89	11.26	12.60	12.62	12.61	12.62	11.84	11.65	10.85	11.23	11.76	11.77	11.70	11.87	11.70	11.77	11.61	11.55	12.00	11.85	11.12	10.44	12.08	11.58	12.62	11.71	24
7	11.56	8.33	10.05	11.02	9.52	9.04	9.22	10.34	10.60	10.13	10.12	10.41	9.31	10.34	10.54	10.05	9.70	8.27	11.36	11.56	11.07	11.31	10.24	10.46	11.56	10.19	24
8	10.64	10.83	9.83	10.45	10.43	10.30	10.15	10.38	10.28	10.91	10.74	10.78	11.03	9.69	9.57	10.06	9.48	10.23	10.17	10.63	10.24	10.28	11.05	10.53	11.05	10.36	24
9	10.29	11.04	11.05	10.81	7.55	10.19	6.10	9.22	8.72	8.32	9.44	10.34	9.13	5.88 M	0.01 M	7.98	7.87	4.00 M	0.02 M	10.75	10.98	11.13	11.19	11.04	11.19	9.66	20
10	10.65	10.90	10.89	9.01	8.49	9.53	8.54	9.31	10.84	10.50	10.85	10.35	7.65	8.29	5.24 M	0.03 M	9.08	9.07	8.46	8.98	9.06	8.88	9.84	10.81	10.90	9.54	22
11	11.35	10.08	10.45	10.88	9.79	8.85	9.43	9.34	9.31	10.33	9.31	10.34	10.84	10.95	11.05	5.18 M	0.01 M	11.78	11.85	11.63	10.04	9.95	9.95	10.05	11.85	10.34	22
12	9.83	10.09	8.62	8.81	10.91	10.80	11.26	9.45	10.10	7.80	8.39	8.25	9.66	8.64	2.16 M	1.42 M	10.15	4.33 M	0.00 M	2.99	5.71	9.89	10.78	10.91	11.26	9.15	20
13	10.74	10.39	10.55	11.17	11.12	11.32	11.12	11.56	10.48	10.13	11.32	10.94	10.02	0.02 M	4.03 M	11.19	0.01 M	1.27 M	10.06	6.04 M	0.01 M	9.68	9.44	6.25 M	11.56	10.66	17
14	0.47 M	10.49	10.77	10.71	10.51	10.08	8.44	8.91	9.87	10.04	10.32	9.71	9.56	5.15 M	0.02 M	11.38	11.61	2.95 M	0.01 M	11.61	11.99	11.43	11.16	10.88	11.99	10.50	19
15	10.52	10.41	10.29	9.42	9.86	9.58	9.61	9.41	9.27	9.49	9.19	9.36	8.65	9.88	9.73	3.63 M	0.01 M	9.80	10.02	10.28	10.43	10.22	8.98	7.06	10.52	9.61	22
16	9.78	8.35	7.58	9.03	9.26	9.08	9.39	9.57	9.72	9.92	8.82	9.49	9.20	9.35	9.45	9.83	5.28 M	0.01 M	6.76 C	9.45	9.60	9.65	8.05	9.35	9.92	9.23	21
17	9.64	9.51	9.52	9.42	7.73	9.14	9.22	7.43	3.72	7.69	10.43	9.15	5.93 M	0.02 M	6.20 M	10.20	2.92 M	0.00 M	0.01 C	0.00 M	0.37 M	6.66	7.08	0.01 M	10.43	8.44	15
18	6.83	9.42	7.82	9.31	9.81	8.68	7.52	7.85	7.55	8.33	8.03	8.89	9.07	0.02 M	5.40 M	6.52 M	0.01 M	6.47 M	10.62	0.01 M	0.61 M	8.20	3.43 M	2.12 M	10.62	8.53	15
19	10.01	9.53	0.01 M	9.47	9.50	10.27	11.91	11.83	11.79	11.41	9.87	0.41 M	3.24 M	9.55	0.00 M	1.79 M	10.74	0.00 M	2.61 M	10.32	2.16 M	3.18 M	9.72	10.83	11.91	10.45	15
20	0.01 M	9.64	11.19	10.52	10.82	10.04	10.95	11.02	9.69	8.50	0.01 M	8.93	6.76 M	0.00 M	5.45 M	5.65 M	0.00 M	3.88 M	6.32 C	0.00 M	5.05 M	10.16	0.00 M	9.47	11.19	10.08	12
21	9.66	0.00 M	6.04 M	9.58	4.34 M	2.02 M	9.40	10.00	10.12	10.26	0.01 M	1.30 M	10.97	2.99 M	0.17 M	9.40	0.25 M	1.89 M	10.00	5.99 M	0.01 M	12.21	11.77	12.06	12.21	10.45	12
22	12.01	12.37	0.03 M	12.58	12.94	12.19	12.05	12.41	12.03	11.82	0.34 M	4.62 M	10.97	0.01 M	1.13 M	11.30	0.01 M	1.45 M	12.14	0.01 M	3.48 M	11.13	0.59 M	6.72 M	12.94	11.99	13
23	11.17	1.77 M	6.06 M	11.26	11.09	0.01 M	10.49	10.32	11.29	6.88 M	0.01 M	10.74	3.93 M	0.00 M	11.35	0.35 M	0.00 M	9.44	0.48 M	3.54 M	10.69	11.11	2.38 M	5.80 M	11.35	10.81	11
24	11.34	11.87	11.99	11.55	10.77	10.62	11.90	12.02	11.86	12.05	2.90 M	8.68	0.03	-0.06	-0.02 M	-0.04	-0.03 M	-0.01 M	1.41	1.90	4.66	7.79	8.81	8.04	12.05	7.86	20
25	8.43	8.72	8.55	8.48	8.70	8.57	5.99	7.12	7.94	8.40	8.43	8.64	8.50	8.08	8.04	0.02 M	8.99	8.19	7.69	7.52	8.10	7.40	9.14	9.26	9.26	8.21	23
26	9.05	9.44	8.75	8.06	6.96	7.04	7.67	7.64	8.84	9.37	9.03	9.39	9.12	8.91	0.00 M	9.21	9.22	10.70	12.18	11.87	11.97	10.18	10.97	9.55	12.18	9.35	23
27	10.11	10.38	7.37	8.06	8.40	9.09	10.59	10.90	10.93	10.59	11.14	10.95	10.74	11.17	11.04	-0.01 M	10.70	11.12	11.55	11.13	9.16	10.21	8.91	9.48	11.55	10.16	23
28	9.55	8.01	9.74	9.05	8.96	9.44	9.14	9.13	10.45	11.06	11.22	11.37	12.04	10.72	7.37	0.65 M	10.00	5.00 M	2.68 M	9.56	10.28	10.50	9.27	10.46	12.04	9.87	21
29	9.83	10.12	10.38	10.39	10.13	10.55	11.34	11.27	11.36	11.19	11.36	4.85 M	2.92 M	9.60	0.00 M	2.74 M	4.60 M	0.00 M	4.14 C	4.86 M	0.69 M	9.86	3.31 M	4.99 M	11.36	10.57	13
30	9.72	4.44 M	4.80 M	10.19	10.05	9.00	10.63	9.70	9.89	9.91	3.96 M	3.60 M	11.56	0.00 M	5.00 M	6.78 M	0.00 M	10.34	10.15	10.79	9.67	9.53	11.89	11.04	11.89	10.25	16
																									13.68	10.01	
Max	12.03	12.37	12.60	12.62	12.94	12.62	12.05	13.00	12.69	12.31	12.26	12.59	12.34	12.70	11.87	11.77	11.61	12.28	12.69	12.37	13.15	13.43	13.68	12.55			
Avg	10.24	10.20	10.02	10.14	9.92	9.96	9.93	10.17	10.23	10.02	9.86	9.72	9.33	9.22	9.72	9.29	10.04	10.11	10.25	9.96	10.06	10.17	10.28	10.33			
Rds	28	27	25	30	29	28	30	30	30	29	24	25	25	20	15	16	16	15	20	22	22	29	25	24			

'I' - Invalid
'M' - Maintenance
'N' - Not Calibrated

'U' - User Data
'O' - Out-of-Control
'W' - Caution

'D' - Process Down
'O' - Out-of-Control
'X' - Excess Emission

'D' - Process Down
'R' - Out-of-Range
'B' - Auto Backfill

Annexure 5: Specimen Calculation- Emission rate of NO_2 from the equivalent stack (considering both stacks as a single stack)

Diameter of a single stack	=	1.4 m
Diameter of the equivalent stack	=	
$\Pi(0.7)^2*2$	=	$\Pi(d/2)^2$
d	=	1.98 m
Air flow rate from the equivalent stack	=	6221.58 m^3/min
	=	6221.58/ $\{\Pi(1.98/2)^2\}$
	=	33.68 m/s
Emission rate of NO_2 from the stack	=	6221.58* 50.81* 60/ 10* 1000
	=	1896.71 kg/hr

ප්‍රජාතාන්ත්‍රික සමාජවාදී ජනරජයේ ගැසට් පත්‍රය
இலங்கைச் சனநாயக சோசலிசக் குடியரசு வர்த்தமானப் பத்திரிகை
The Gazette of the Democratic Socialist Republic of Sri Lanka

අති විශෙෂ   அதிவிசேஷமானது   EXTRAORDINARY

අංක 850/4 - 1994 දෙසැම්බර් 20 වැනි අඟහරුවාදා - 1994.12.20
இல. 850/4 — 1994 ஆம் ஆண்டு திசெம்பர் மாதம் 20 ஆம் திகதி செவ்வாய்க்கிழமை
No. 850/4 – TUESDAY, DECEMBER 20, 1994

PART I : SECTION (I) – GENERAL

Government Notifications

L. D. – B. 4/81.

THE NATIONAL ENVIRONMENTAL ACT, No. 47 OF 1980

BY virtue of the powers vested in me by Section 23W of the National Environmental Act, No. 47 of 1980, I, Srimani Athulathmudali, Minister of Transport, Highways, Environment and Women's Affairs, do by this Order, prohibit with effect from 01st January, 2000, the use of the material specified in the Schedule hereto, being used for any process, trade or industry as being Ozone depleting materials and substances which will endanger the quality of the Environment;

Provided that the said materials specified in the Schedule hereto, may continue to be used until 01st January, 2005, for the limited purpose of servicing equipment or industrial plants already in operation or which have been installed prior to 01st January, 2005.

Schedule

Code	*Symbol*	*Substance*
CFC – 11 (R 11)	$CFCl_3$	Trichlorofluoromethane
CFC – 12 (R 12)	CF_2Cl_2	Dichlorodifluoromethane
CFC – 113 (R 113)	$C_2F_3Cl_3$	Trichlorotrifluoroethane
CFC – 114 (R 114)	$C_2F_4Cl_2$	Dichlorotetrafluoroethane
CFC – 115 (R 115)	C_2F_5Cl	Chloropentafluoroethane
Halon – 1211	CF_2BrCl	Bromochlorodifluoromethane
Halon – 1301	CF_3Br	Bromotrifluoromethane
Halon – 2402	CF_4Br_2	Dibromotetrafluoroethane
CFC – 13	CF_3Cl	Chlorotrifluoromethane
CFC – 111	C_2FCl_5	Pentachlorofluoroethane
CFC – 112	$C_2F_2Cl_4$	Tetrachlorodifluoroethane
CFC – 211	C_3FCl_7	Heptachlorofluoropropane
CFC – 212	$C_3F_2Cl_6$	Hexachlorodifluoropropane
CFC – 213	$C_3F_3Cl_5$	Pentrachlorotrifluoropropane
CFC – 214	$C_3F_4Cl_4$	Tetrachlorotetrafluoropropane
CFC – 215	$C_3F_5Cl_3$	Trichloropentafluoropropane
CFC – 216	$C_3F_6Cl_2$	Dichlorohexafluoropropane
CFC – 217	C_3F_7Cl	Chloroheptafluoropropane
	CCl_4	Carbon Tetrachloride (tetrachloromethane)
	$C_2H_3Cl_3$	Methyl Chloroform (1, 1, 1 – Trichloroethane)

SRIMANI ATHULATHMUDALI,
Minister of Transport, Highways,
Environment and Women's Affairs.

Colombo,
25th October, 1994.
11-193/1

2A – D 034203 (94/10)

L.D.B. 4/81. 850/4 – 20.12.1994

NATIONAL ENVIRONMENTAL ACT, No. 47 OF 1980

REGULATIONS made by the Minister of Transport, Highways, Environment and Women's Affairs under section 32 of the National Environmental Act, No. 47 of 1980, read with section 23E of that Act.

SRIMANI ATHULATHMUDALI,
Minister of Transport Highways,
Environment and Womens' Affairs.

Colombo, 5th October, 1994.

Regulations 10

1. These regulations may be cited as the National Environmental (Appellate Procedure) Regulations, 1994.

2. These regulations shall apply to appeals against the refusal to grant, the refusal to renew, the suspension or the cancellation of an environmental protection licence under section 23B or 23D of the National Environmental Act, No. 47 of 1980 (hereinafter in these regulations referred to as "the Act") by the authority or any government department, corporation, statutory board, local authority or public officer to whom the Authority may have delegated the power to issue, suspend, renew or cancel such licence under and in terms of section 26 of the said Act.

3. Appeals under section 23E against the refusal, refusal to renew, suspension or cancellation of an environmental protection licence shall be lodged with the Secretary to the Ministry of the Minister in charge of the subject of Environment within thirty days after the date of the notification of decision appealed against.

4. (1) (a) Every Appeal to which these regulations apply, shall be in writing and be signed by the appellant and where the appellant is a body of persons be signed by a Director, Secretary or other authorised officer of that body;

(b) be dated and lodged with the Secretary to the Minister within the stipulated time;

(c) have annexed to it a copy of the decision appealed against;

(d) set out concisely in duly numbered paragraphs the grounds of appeal;

(e) set out the relief which the appellant seeks; and

(f) set out the names and addresses of any persons or bodies of persons who were parties to any hearing or inspection carried out by the authority, government department, corporation, statutory body, local authority or public officer as the case may be.

(2) Any appeal that does not comply with the requirements of regulation 4 (1) shall not be processed until the said requirements are complied with. The Secretary shall notify the appellant of non-compliance in writing and where the appellant fails to rectify such omission within the time stipulated in the notice, or within such extension of time as the Secretary may, on application grant, the Secretary shall reject the appeal.

5. All appeals received shall be entered on a register to be maintained by the Secretary for such purpose. Such register or an extract thereof duly authenticated by the Secretary shall be a public document open for public inspection at the office of the Ministry of the Minister in charge of the subject of Environment during any working day.

6. Upon the lodging of an appeal, the Secretary shall call for the entire record relating to the decision under appeal from the authority, government department, corporation, statutory body, local authority or public officer as the case may be and they shall forthwith forward the said record to the Secretary.

7. The Secretary shall thereafter notify in writing the persons whose names and addresses are disclosed in the appeal that an appeal has been lodged and that the appeal, may be perused at his office during a period of ten working days from the date of notice and shall further inform such persons that he will entertain written objections or comments to the appeal during that period:

Provided however, where the number of persons disclosed in the appeal exceed 20, the Secretary may, in his discretion, publish the notice in an English, Sinhala or Tamil newspaper.

8. At the end of the period referred to in regulation 7, the Secretary shall notify the appellant, that objections or comments have been received from the persons disclosed in his appeal and that the same may be perused at his office during a period of ten days from the date of such notification and the appellant may respond in writing if he so desires to such objections or comments, during that period.

9. At the conclusion of the period referred to in regulation 8, the Secretary may in his discretion, notify the appellant and the persons who have made objections or comments under regulation 7, to appear before him at a formal hearing of the appeal on such date and time as may be set out in such notice.

Annexure 7: Pasquill- Gifford Curves

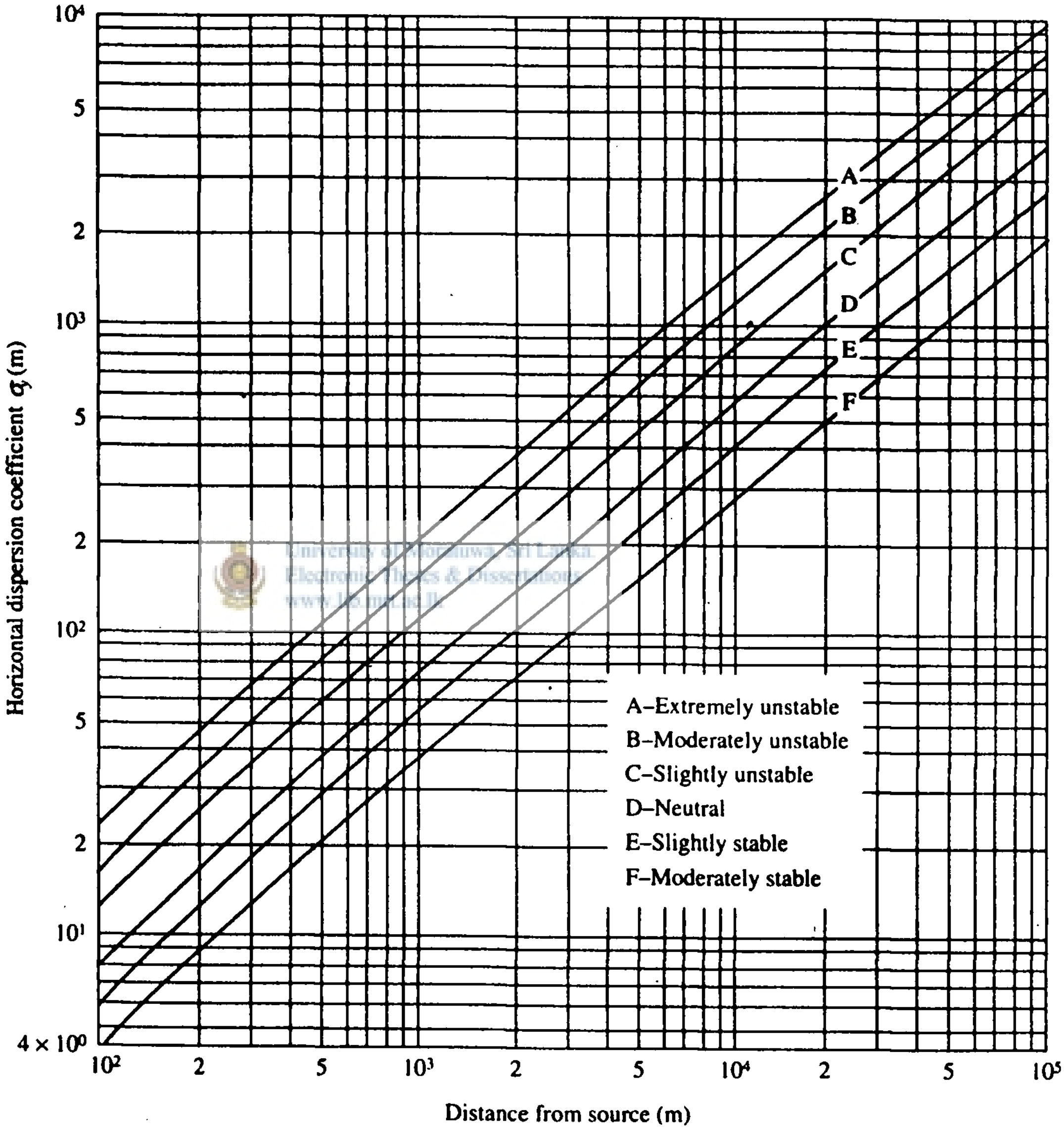


Figure 8.24 Correlations for σ_y based on the Pasquill stability classes A–F (Gifford, 1961). These are the so-called Pasquill–Giffo curves.

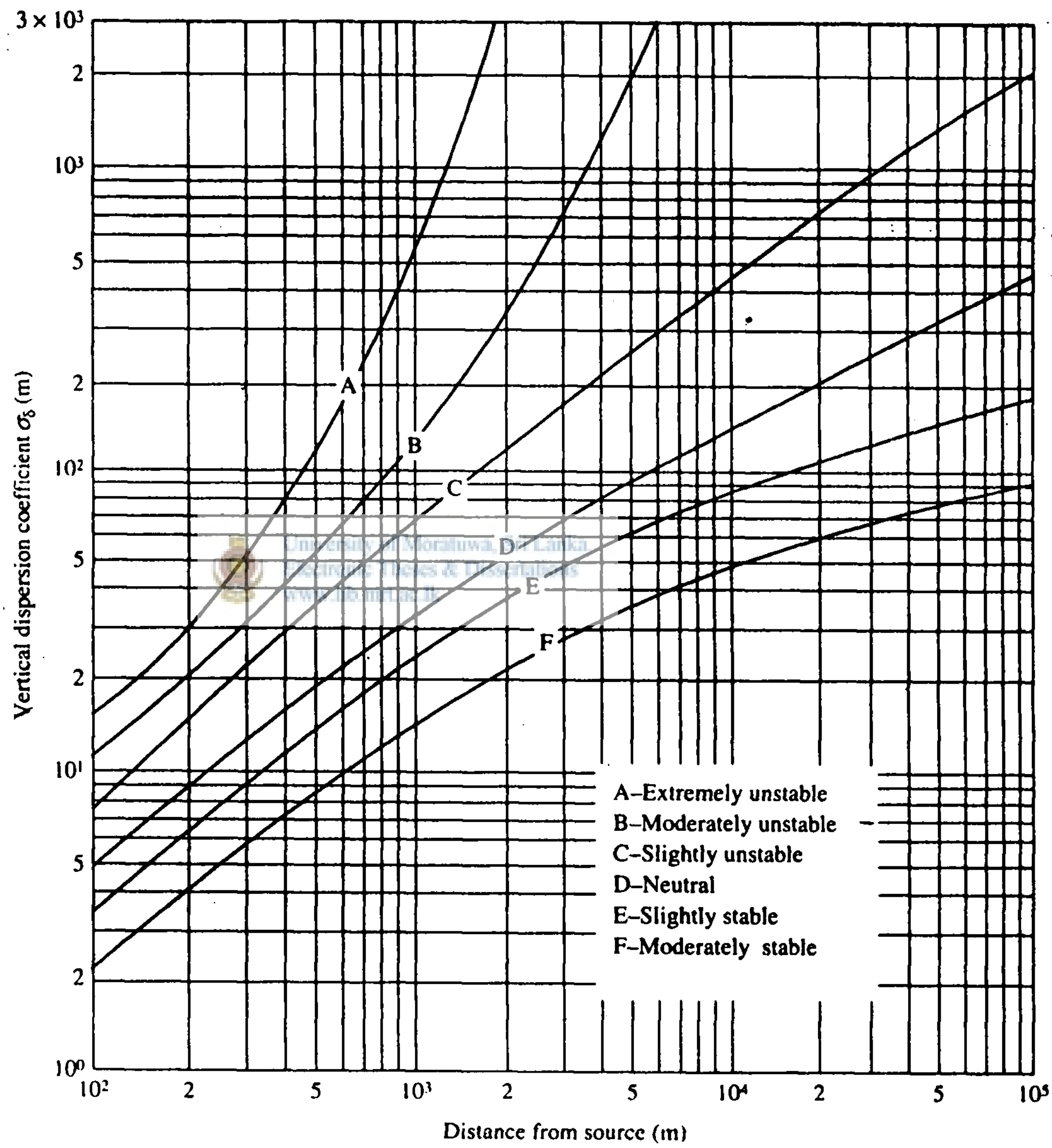
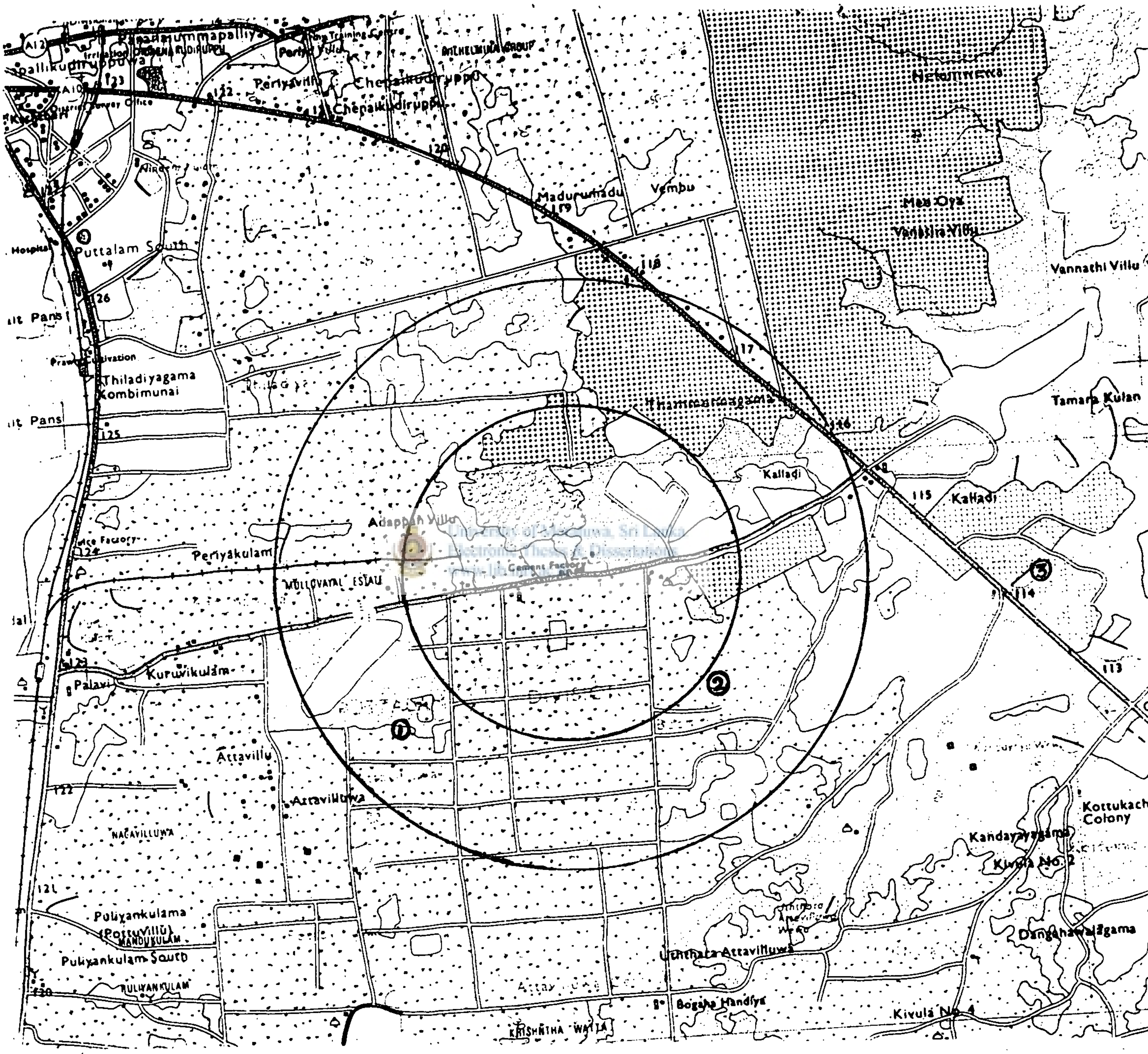


Figure 8.25 Correlations for σ_z based on the Pasquill stability classes A–F (Gifford, 1961). These are the so-called Pasquill–Gifford curves.

Annexure 8: Area map, monitoring locations and the area of highest damage



Scale 1:50000

Monitoring locations

1- Air force camp 2- School ground 3- Guest house

Area between the two circles is the area of highest damage (1.5- 2.5 km)

Annexure 9: Output from the SCREEN3 model

10/31/06
13:16:14

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 *** SCREEN3 MODEL RUN ***
 *** VERSION DATED 96043 ***

Comparison with AUSPLUME results- Holcim stack

SIMPLE TERRAIN INPUTS:
   SOURCE TYPE                =        POINT
   EMISSION RATE (G/S)        =      167.610
   STACK HEIGHT (M)           =      80.0000
   STK INSIDE DIAM (M)        =       1.4000
   STK EXIT VELOCITY (M/S)    =      27.3876
   STK GAS EXIT TEMP (K)      =     418.1400
   AMBIENT AIR TEMP (K)       =     298.0000
   RECEPTOR HEIGHT (M)        =        .0000
   URBAN/RURAL OPTION         =        RURAL
   BUILDING HEIGHT (M)        =        .0000
   MIN HORIZ BLDG DIM (M)     =        .0000
   MAX HORIZ BLDG DIM (M)     =        .0000

THE NON-REGULATORY BUT CONSERVATIVE BRODE 2 MIXING HEIGHT OPTION WAS SELECTED.
THE REGULATORY (DEFAULT) ANEMOMETER HEIGHT OF 10.0 METERS WAS ENTERED.

   STACK EXIT VELOCITY WAS CALCULATED FROM
   VOLUME FLOW RATE =   42.160000    (M**3/S)

BUOY. FLUX =   37.811 M**4/S**3;  MOM. FLUX =  261.939 M**4/S**2.

*** FULL METEOROLOGY ***

**********************************
*** SCREEN DISCRETE DISTANCES ***
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*** TERRAIN HEIGHT OF    0. M ABOVE STACK BASE USED FOR FOLLOWING DISTANCES **
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DIST (M)	CONC (UG/M**3)	STAB	U10M (M/S)	USTK (M/S)	MIX HT (M)	PLUME HT (M)	SIGMA Y (M)	SIGMA Z (M)	DWASH
500.	334.7	1	3.0	3.5	300.0	174.14	116.19	108.05	NO
1000.	705.2	1	1.0	1.2	366.1	362.43	223.76	460.97	NO
1500.	511.3	1	1.0	1.2	366.1	362.43	308.88	1073.64	NO
2000.	456.4	2	1.5	1.7	276.3	268.29	290.82	239.93	NO
2500.	409.8	2	1.0	1.2	369.7	362.43	357.52	309.38	NO
3000.	379.0	3	2.0	2.5	225.4	212.68	281.56	171.25	NO
3500.	360.6	3	1.5	1.8	268.5	256.90	324.52	198.83	NO
4000.	345.3	3	1.5	1.8	268.5	256.90	364.98	223.07	NO
4500.	323.0	3	1.5	1.8	268.5	256.90	404.97	247.21	NO
5000.	306.7	3	1.0	1.2	355.7	345.35	448.10	277.04	NO

```
DWASH=    MEANS NO CALC MADE (CONC = 0.0)
DWASH=NO  MEANS NO BUILDING DOWNWASH USED
DWASH=HS  MEANS HUBER-SNYDER DOWNWASH USED
DWASH=SS  MEANS SCHULMAN-SCIRE DOWNWASH USED
DWASH=NA  MEANS DOWNWASH NOT APPLICABLE, X<3*LB

   ***************************************
   *** SUMMARY OF SCREEN MODEL RESULTS ***
   ***************************************
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CALCULATION        MAX CONC     DIST TO    TERRAIN
 PROCEDURE        (UG/M**3)     MAX (M)     HT (M)
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SIMPLE TERRAIN       705.2          1000.         0.

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** REMEMBER TO INCLUDE BACKGROUND CONCENTRATIONS **
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