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MEMORANDUM CIRCULAR
NO. 2008 - 003

FOR : ALL REGIONAL DIRECTORS
AIR POLLUTION CONTROL DIVISION CHIEFS

SUBJECT : GUIDELINES FOR AIR DISPERSION MODELLING

To guide you in the assessment of the potential of air pollution sources to cause air pollution for permitting purposes under the Clean Air Act and its Implementing Rules and Regulations, you are hereby provided with the attached Guidelines for Air Dispersion Modelling.

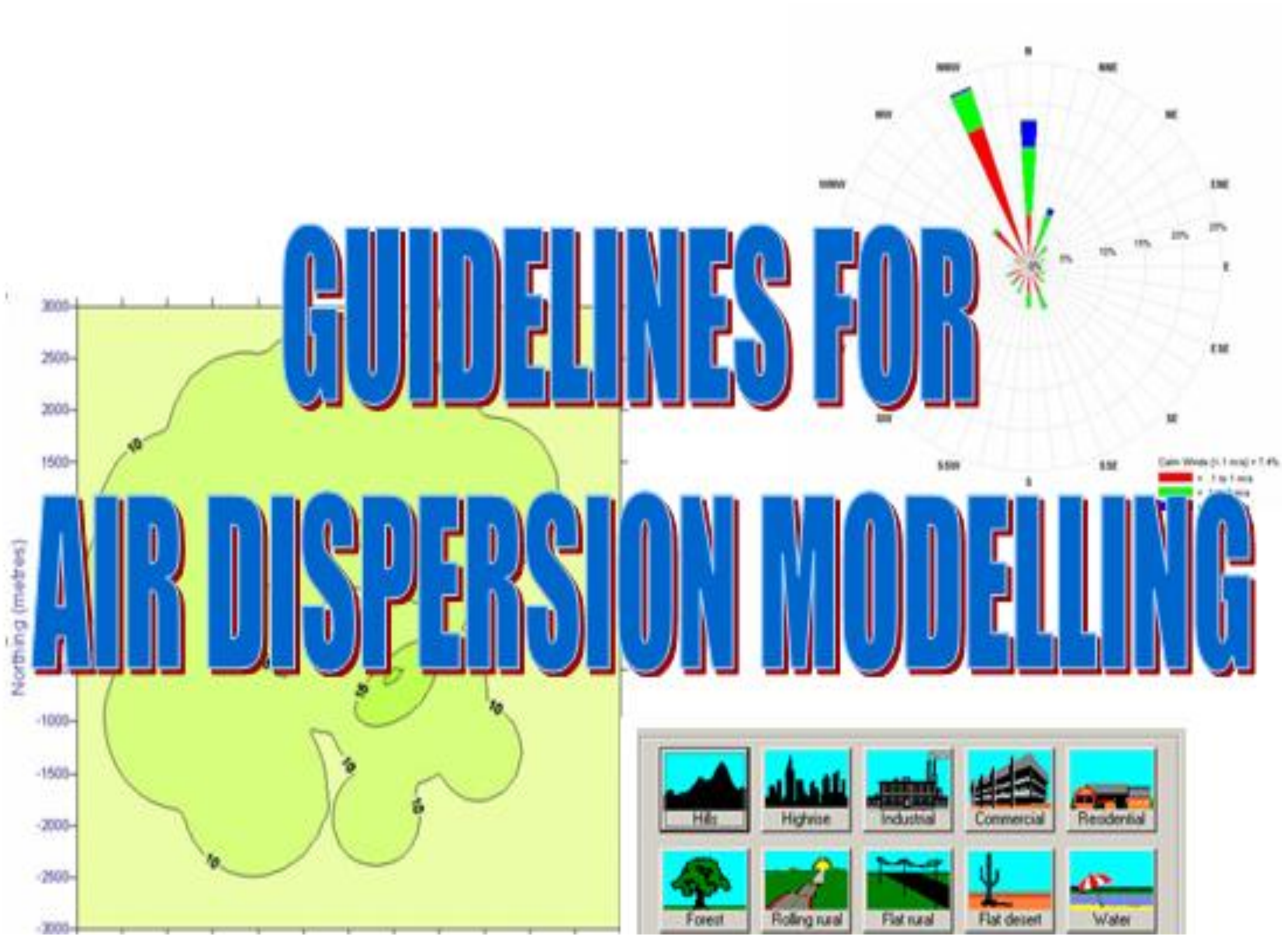
The document serves to ensure that a consistent approach is used for the dispersion modeling of emission sources nationwide.

All concerned are enjoined to utilize the Guidelines on Air Dispersion Modelling and to share information regarding this Memorandum Circular to concerned agencies, industries and other stakeholders.

JULIAN D. AMADOR

ENVIRONMENTAL MANAGEMENT BUREAU

GUIDELINES FOR AIR DISPERSION MODELLING



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Abbreviations

Abbreviation	Abbreviation Definition
AERMIC	American Meteorological Society/EPA Regulatory Model Improvement Committee
BACT	Best Available Control Technology
BID	Buoyancy-induced Dispersion
BPIP	Building Profile Input Program
CAA	Clean Air Act
EIS	Environmental Impact Statement
EMB	Environmental Management Bureau
GEP	Good Engineering Practice
GRDRISM	Gradual plume rise
IRR	Implementing Rules and Regulations
IRRI	International Rice Research Institute
ISCST	Industrial Source Complex Model-Short Term
MCR	Maximum Continuous Rating
MSGPRO	Missing data processing routine
NAAQG	National Ambient Air Quality Guidelines
NOBID	No buoyancy-induced dispersion
NOSTD	No stack-tip downwash
PAGASA	Philippines Atmospheric, Geophysical & Astronomical Services Administration
PRIME	Plume Rise Model Enhancements
SIZ	Structure Influence Zone
UTM	Universal Transverse Mercator

1 Introduction

The purpose of this document is to provide guidance on carrying out atmospheric dispersion modelling in the Philippines in order to meet the requirements under the RA 8749: the Philippines Clean Air Act of 1999 (CAA) and the independent rules and regulations.

Where the recommended approaches are not suitable for a particular modelling exercise, the reasons for deviating from them should be clearly explained in the modelling report submitted to the Environmental Management Bureau (EMB). The aims of these guidelines is to provide a consistent approach to undertaking dispersion modelling in the Philippines using a tiered approach and consequently to improve the accuracy of modelling results so they can be relied upon when considering the potential adverse impacts of emissions to air.

The guidelines set out a recommended hierarchal approach to dispersion modelling in the Philippines, EMB approved dispersion models for use in the Philippines, when to use them, the nature of input data required, and how to get the most accurate results for the level of assessment required. The guidance is designed to assist those undertaken the atmospheric dispersion modelling, and those involved in reviewing modelling outputs for auditing Environmental Impact Statements and CAA permit applications.

It should be recognised that modelling is a complex process and that personnel trained in atmospheric dispersion modelling and the approved models should be the ones undertaking the dispersion modelling conforming to the recommended good practice guidance provided in this document.

Guidance is provided for:

- Which model is most appropriate for the particular circumstances in accordance with the EMB tiered approach for conducting dispersion modelling
- What data to put into the model (including emissions data and meteorological data)
- How to account for background ambient air concentrations
- How to run a model effectively
- Pitfalls to watch out for
- How to understand the accuracy of modelling results.

Throughout the guidelines personnel undertaking the modelling are encouraged to:

- Use the best available information
- Comply with the recommendations made in this document
- Create an auditable trail of the work undertaken.

The guidelines are not intended to replace the detailed user manuals that accompany each dispersion model and these should still be consulted.

1.1 What is Dispersion Modelling

An atmospheric dispersion model is a:

- Mathematical simulation of the physics and chemistry governing the transport, dispersion and transformation of pollutants in the atmosphere; and
- Means of estimating downwind air pollution concentrations given information about the pollutant emissions and nature of the atmosphere.

Dispersion models can take many forms. The modern air pollution models are computer programs that calculate the pollutant concentration downwind of a source using information on the:

- Contaminant emission rate
- Characteristics of the emission source
- Local topography
- Meteorology of the area
- Ambient or background concentrations of pollutant.

The process of air pollution modelling contains four stages (data input, dispersion calculations, deriving concentrations, and analysis). The accuracy and uncertainty of each stage must be known and evaluated to ensure a reliable assessment of the significance of any potential adverse effects.

1.2 What can dispersion modelling be used for?

Dispersion models can be set up to estimate downwind concentrations of contaminants over varying averaging periods – either short term (one-hour) or long term (annual). In the Philippines, the most common use of dispersion modelling is to assess the potential environmental and health effects of emissions to air from proposed industrial or trade premises as part of the Environmental Impact Statement (EIS) process.

Models are particularly valuable for assessing the impacts of discharges from new activities and to estimate likely changes as a result of process modifications. Modelling results can also be used for:

- Assessing compliance of emissions from proposed plants with air quality guidelines and standards as part of the EIS and permitting process;
- Assessing the compliance of emissions for additions to existing plants already permitted;
- Determining appropriate stack heights;
- Managing existing emissions;
- Designing ambient air monitoring systems including identifying the optimum locations where site monitors;
- Identifying the main contributors to existing air pollution problems; Estimating the influence of geophysical factors on dispersion.
- Evaluating mitigation strategies in accordance with BACT (Best Available Control Technology); and

- Estimating the influence of geophysical factors on dispersion.

1.3 What can't dispersion models do?

Even the most sophisticated atmospheric dispersion model cannot predict the precise location, magnitude and timing of ground-level concentrations with 100% accuracy. However, most models used today (especially the regulatory approved models (USEPA and VicEPA) have been through a thorough model evaluation process and the modelling results are reasonably accurate, provided an appropriate model and input data are used.

Errors are introduced into results by the inherent uncertainty associated with the physics and formulation used to model dispersion, and by imprecise input parameters, such as emission and meteorological data. The most significant factors that determine the quality and accuracy of the results are:

- The suitability of the model for the task;
- The availability of accurate source information;
- The availability of accurate meteorological data; and
- The availability of accurate background concentration data.

The cause of model uncertainty and the methods to overcome the lack of appropriate data is covered late in these guidelines.

2 Why is dispersion modelling required?

2.1 Regulatory requirements for dispersion modelling

2.1.1 RA 8749: the Philippines Clean Air Act of 1999

RA 8749: the Philippines Clean Air Act of 1999 (CAA) set s out In Section 12 ambient air quality guideline values and standards. The short term guidelines specified in Table A For National Air Quality Guidelines for Criteria Pollutants are maximum limits represented by 98 percentile values not to be exceeded more than once a year. For a proposed new plant that requires a permit atmospheric dispersion modelling will need to be undertaken to demonstrate that these guideline values will be complied with. All ground level concentrations predicted by the dispersion modelling will need to be converted to 98 percentiles to allow a direct comparison to be made with the CAA air quality guidelines.

Annual arithmetic mean guidelines are also provided for some pollutants (PM10, TSP and Lead). In order to undertake annual arithmetic mean modelling at least three years of meteorological data is required.

2.1.2 Implementing Rules and Regulations

The implementing rules and regulations (IRR) enacted under the CAA require dispersion modelling to be undertaken for proposed new plants or if there has been any modifications to existing sources at plants such as the introduction of new additional sources or changes to the control equipment fitted.

IRR Rule X, Section 3. Increment Consumption states that:

"No new source may be constructed or existing source modified if emissions from the proposed source or modification will, based on computer dispersion modeling, result in;

- Exceedance of the National Ambient Air Quality Guideline Values; or
- An increase in existing ambient air levels above the levels shown below:

- *PM-10, annual arithmetic mean 17 µg/Ncm (micrograms per Normal cubic meter)*
- *PM-10, 24-hr maximum 30 µg/Ncm*
- *Sulfur Dioxide, annual arithmetic mean 20 µg/Ncm*
- *Sulfur Dioxide, 24-hr maximum 91 µg/Ncm*
- *Nitrogen Dioxide, annual arithmetic mean 25 µg/Ncm"*

If the dispersion modelling demonstrates, that these requirements will not be met for a new or a proposed modification to a plant, then that new plant or modification will not be permitted. The first test being that the highest 98 percentiles ground level concentrations predicted by dispersion modelling do not exceed the National Ambient Air Quality Guidelines (NAAQG). If they exceed the guidelines then the highest predicted 98 percentile ground level concentration should not exceed the guidelines by the concentrations specified in Rule X.

The dispersion modelling required to be performed will be undertaken using a dispersion model approved by the Environmental Management Bureau as set out in IRR Rule XIX, Section 3. Application for Permit to Operate which states that:

"(c) The project proponent shall conduct an air quality impact analysis using Bureau-approved computer dispersion models and techniques."

The hierarchy for dispersion modeling set out in these guidelines establishes the models approved by EMB and the situations for which they can be used in a valid manner.

IRR Rule XIX, Section 3. Application for Permit to Operate (c) (continued) shall

"The impact analysis shall estimate the resulting ambient air concentrations for all significant pollutants from the facility, and shall include the existing ambient air concentrations as a baseline."

There is currently limited baseline/background ambient air data for the Manila area and these guidance notes provides a hierarchy of routines for incorporating background ambient air data in the dispersion modelling. This hierarchy is set out in section 3 of these guidelines.

The impact analysis including the outputs from dispersion modeling will be used by the Bureau, together with other relevant information, to determine if the proposed construction or a new plant or modification to emission sources will result in a violation of an applicable air quality standard.

As well as isopleth diagrams and a summary of the dispersion modeling being included in the EIS the full dispersion modeling input and output files will need to be supplied as well to enable the EMB to evaluate the validity of the modeling undertaken. This provision of appropriate information on the dispersion modeling undertaken to the Bureau is captured by IRR Rule XIX, Section 5. Application for Permit to Operate(c) which states

"The statement of compliance [with Ambient Air Quality Standards] shall be supported by dispersion modeling data using modeling techniques and sampling approved by the Bureau."

Dispersion modeling is also required to be used under certain circumstances to determine the best locations to install ambient air monitors.

Under IRR Rule XIX, Section 5 Application for Permit to Operate "(c) (contd.) For cases in which source sampling and analysis is not practical*, the Bureau may approve the use of actual ambient air test data to demonstrate compliance with the Ambient Air Quality Standards, so long as the location and conditions of the testing conform to a `worst case` scenario as demonstrated by air dispersion modeling."

The best location to install ambient air monitors would be based on the location the highest maximum ground level concentrations predicted by the dispersion model. This use of dispersion modeling to identify appropriate locations for the installation of ambient air monitors is also covered by Rule XXVI Source Specific Ambient Air Quality Standards which requires sampling for compliance with National Ambient Air Quality Standards

"shall be done at the location of highest expected concentration. Location shall be determined using dispersion modeling."

There is currently no requirement for undertaking dispersion modeling to determine the impacts on ambient air quality from existing plants as part of the permit renewal process.

Recommendation 1: That existing plants above a certain size threshold as determined by EMB should be required as part of their permit renewal process undertake dispersion modelling in order to demonstrate that they comply with the national ambient air quality guidelines. For example a coal or bunker C fired boiler based on the heating value of the fuel over 10MW is required to undertake dispersion modelling. This is the current threshold for undertaking an EIS.

3 Approved Models using a Tiered Approach

3.1 Tiered Approach to Modelling Assessment

The modelling assessment will be carried out following a tiered approach to assess contaminant concentrations against CAA air quality guidelines and standards. This tiered approach follows the approach recommended by the US Environmental Protection Agency and includes:

- Screening-level dispersion modelling techniques conducted using worst-case input data rather than site-specific data, and
- Refined level dispersion modelling techniques conducted using site specific meteorological data or derived regional meteorological data.

A fundamental assumption of the tiered approach to model selection is that the simpler modelling techniques always yielded more conservative results. It was assumed that screening level models would always predict higher ground-level concentrations than refined modelling techniques, and that the refined models would predict higher impacts than the 'best-estimate' models.

3.2 Tier 1 Screening of single sources

Tier 1 involves the US EPA SCREEN3 model which requires no local meteorological data. This model is normally used as an initial screening tool to assess single sources of emissions. Screening model requirements are the least intensive but produce the most conservative results. SCREEN3 is for a single source. It can be applied to multi-source facilities by conservatively summing the maximum concentrations for the individual emission sources, though this approach is not recommended. Screening results are compared against the air quality guidelines and standards at the 1 hour averaging time. The refined models (Tiers 2, 3 and 4) discussed in the following sections, have much more detailed options allowing for greater characterization and more representative results.

To allow a comparison with the 24-hour average air quality guidelines the 1-hour averaging time can be converted to a 24 hour average using the conversion methodology set out in Appendix B.

The maximum ground level concentration predicted using this screening method must be less than 50% of the relevant national ambient air quality guideline or standard. If higher than 50% of the guideline more refined modelling is required and the modeller should either go to Tier 2 or 3.

If more than one point, area or volume source at the plant subject to the assessment the modeller should go to Tier 2.

Note 1. This is currently the most common approach used in undertaking dispersion modelling assessment in the Philippines. It is fine for single source and when the predicted ground level concentrations are low (below 50% of the NAAQGs). However it has no ability to handle sites with multiple sources and real time meteorological data.

3.3 Tier 2 Refined model using screening meteorological data

Tier 2 involves dispersion modelling with the AUSPLUME model incorporating the PRIME building downwash algorithms (AUSPLUME Version 6). The model would be run using screening meteorological data (metsamp.met) that comes with the model. This allows plants with multiple sources and the potential for building influence (downwash effects) to be assessed down a single wind direction.

If a single wind direction is used the model has no ability to assess the influence of building heights on the dispersion of the plume, other than for that wind direction. To allow building downwash effects to be assessed the screening meteorological data set needs to be altered so that it provides wind directions for 360 degree at 10 degree intervals (36 times 10 degree sectors) rather than from a single wind direction from the north which are its defaults setting.

AUSPLUME has been selected as it contains the US EPA's latest algorithms that allow building wake effects on the dispersing plumes to be assessed in the analysis and is an easier model to use than ISC-PRIME. This is an important consideration for sites with multiple sources on a building or buildings.

Recommendation 2: A screening meteorological data set needs to be developed that provides wind direction for 360 degrees (36 sectors at 10 degrees is the minimum), to enable building downwash effects to be evaluated, to enable the Tier 2 assessment to be undertaken.

Note 2. This is the second most common approach to undertake dispersion modelling in the Philippines. In most instances it is undertaken only for on wind direction which means building downwash effects can not be adequately evaluated. This approach is very limited and wi only produce worst case numbers which, will tend to result in the fiddling of input parameters to get the desired ground level concentrations.

The maximum ground level concentration predicted using this screening method must be less than 50% of the relevant national ambient air quality guideline or standard. If higher than 50% of the guideline more refined modelling is required and the modeller should either go to Tier 3 or 4.

One hour highest maximum ground level concentrations can be predicted using this data, but there is not sufficient meteorological data to enable 24-hour average concentrations to be predicted by the model. To allow a comparison with the 24-hour average air quality guidelines the 1-hour averaging time can be converted to a 24 hour average using the conversion methodology set out in Appendix B. 98 percentile ground level concentrations can not be predicted using this meteorological data. Only the highest maximum ground level concentrations can be predicted using this approach as there is inefficient meteorological data (hours) to enable 98 percentiles to be accurately predicted.

3.4 Tier 3 Refined model using EMB meteorological data

Tier 3 uses initially AUSPLUME with meteorology obtained from EMB's ambient air monitoring network in the Metro-Manila region. Pre-processed meteorological data sets for each of the stations prepared by the EMB will be made available to modellers. The AUSPLUME model will be able to be utilised to conduct the assessment to determine the level of the proposed developments impacts on the surrounding environment, including building downwash effects and terrain effects on the discharged plumes for one hour, 24-hour and annual averaging times, without the need for the use of conversion factors. One hour 98 percentile ground level concentrations can be predicted in this Tier.

This AUSPLUME model is used to predict near field effects out to 4 kilometres from the site. However most of the significant effects of the emissions will occur with in 1-2 kilometres of the site. However if complex terrain is presented then a more sophisticated dispersion model such as AERMOD or CALPUFF will need to be used in this Tier. The model selected will be up to the modeller and the reasons for its selection will need to be discussed in the modelling report.

Note 3. Meteorological data suitable to develop regional meteorological data sets for dispersion modelling is not available and without this data there is no ability to undertake dispersion modelling with AUSPLUME, CALPUFF and AERMOD. In addition for CALPUFF and AERMOD digitised terrain data is also required.

Recommendation 3: EMB to commission the development and publication of a meteorological data sets from the ambient air monitoring network for Manila to enable Tier 3 dispersion modelling to be undertaken with AUSPLUME

If the national ambient air quality guidelines are exceeded then a Tier 4 assessment will be required.

The ability to assess local air quality using a more appropriate effects-based averaging time means the refined air dispersion models provide a more representative assessment of health and environmental impacts of air emissions from a facility.

The 98 percentile ground level concentration predicted using EMB meteorological data with background concentrations included must be less than the relevant national ambient air quality guideline or standard. If higher than the guideline more refined modelling is required and the modeller should either go to 4.

3.5 Tier 4 Sophisticated modelling using site specific meteorological data

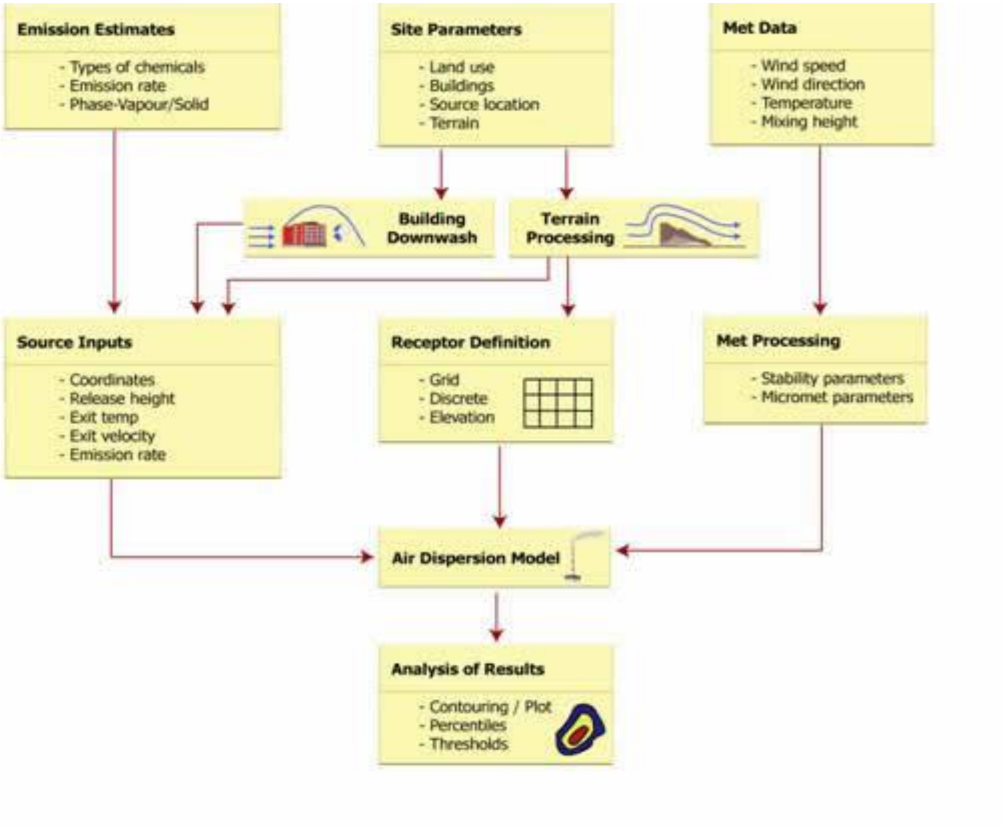
An even more representative modelling scenario would be using the most refined modelling techniques (sophisticated models like AERMOD and CALPUFF) to assess the impact of contaminant emissions. These models use local meteorological data that is based on the wind fields of the area and include terrain effects on the wind directions. Local meteorological data sets including site-specific parameters, terrain data and meteorological characteristics should be used, as it more accurately reflects local conditions. Local meteorological data would be provided by the proponent and agreed to by the EMB. Ideally a minimum of three years of local meteorology should be used in the dispersion modelling. However due to the difficulty in obtaining local meteorological data the EMB may accept a single year of site specific data, along with corroborating evidence that the data was recorded at or near the site being assessed.

Any proponent may choose to go directly to the more refined modelling techniques (Tier 3 or 4) and skip the initial Tier 1and 2 screening methods if they so choose. In some situations, such as with tall stacks for large thermal energy plants, the EMB may require a proponent to proceed to Tier 3 or 4 directly.

4 Data requirements for models

4.1 General Overview

A general overview of the process typically followed for performing an air dispersion modelling assessment is present in Figure 1 below. The figure is not meant to be exhaustive in all data elements, but rather provides a picture of the major steps involved in an assessment.



- Figure 1 Overview of data requirements for dispersion modelling

4.2 Sources

There are four main types of sources used in dispersion modelling:

- Point source − discharges from a small opening such as a stack or vent Point sources require the specification of emission temperature and exit velocity in addition to emission rates.
- Area source − a source with a large surface area, such as a landfill surface, contaminated site, a pile of solid material, or a liquid surface (pond, tank, lagoon). Some models assume that individual area sources have square dimensions. In practice, sources are usually irregular in shape. You can approximate these irregular shapes by using an appropriate selection of a number of square area sources. However, AUSPLUME, AERMOD and CALPUFF also allow area sources to be rectangular, circular or polygons with irregular angles. The rectangular area sources can be rotated to any

angle rather than oriented parallel to a north-south grid. SCREEN3 allows definition of a rectangular area.

- Line source − a long, narrow source such as a roadway, conveyor belt, or roofline vent along a long, narrow building (usually a line source must be redefined as a chain of volume sources for modelling). AERMOD and CALPUFF can handle line sources.
- Volume source − bulky, diffuse source such as emissions from within a building. The size of volume sources is specified using initial horizontal and vertical spreads. These depend on the type of volume source and what the source is representing (such as a ridge-line vent), and can be obtained from tables in the user's guide or online help system for each model.
- Flare sources - used as control devices for a variety of sources eg landfill gas flaring. SCREEN3 supports flares directly through its flare source type.

4.2.1 Source Grouping

Source groups enable modelling results for specific groups of one or more sources. The default in AUSPLUME, AERMOD and CALPUFF is the creations of a source group "ALL" that considers all the sources at the same time. For SCREEN3 only a single source can be modelled.

4.3 Emission rates

Emission rates can be a major source of error and inconsistency in any modelling analysis. For inert pollutants, the modelled concentration is directly proportional to the emission rate, so any errors in the emission rate data translate directly into errors in the model results. It is therefore important to use emission rates that are as accurate as possible.

Sources of emission data include:

- Measurements from a particular (or similar) source
- Manufacturer's specifications or process information
- Published data (e.g. US EPA's AP-42 database)
- Regulatory authority files and data
- Calculated emissions from emission models.

Emission rate data should ideally be sourced from measurements undertaken at either the site in question (for an existing site) or a similar site (if available) for a proposed new development. Alternatively emission rates may be calculated from manufacturer's specifications or directly using industrial process knowledge. When no appropriate measured emission rates are available, published emission factors can be useful. Published emission factors give the mass of pollutants discharged per mass of fuel consumed, or product processed. They are useful as a first estimate of emission rates for pollutants where collection of actual emission rate measurements is impractical or impossible. Examples of these include the US EPA's AP-42 Emission Factors (www.epa.gov/ttn/chief/) or the UK Emission Factors Database (www.naei.org.uk/emissions/).

As a general guide for simple dispersion model scenarios with only one or two sources, the maximum measured emission rate from the source(s), or the calculated emission rate corresponding to maximum production or fuel burning rate, is typically used for dispersion calculations. The combustion appliances operating at maximum continuous rating (MCR).

4.3.1 Variable emission rates

If your sources exhibit variable emission rates, either over short- or longer-term periods, it may be important to consider programming the model to simulate the variation in the emissions. This would reduce the possibility of the model over-predicting long-term (longer than one-hour) averages, which could occur if the maximum emission rate was assumed to apply for 24 hours per day, 365 days per year.

There are a number of ways in which emission rates may vary. Some of the processes that can drive the need to use variable emission rates are when:

- A process does not operate 24 hours per day
- The rate of process (e.g. rate of combustion or production) varies throughout the day
- When the emission rate (e.g. odour or dust) varies with temperature or season
- The emission is from a large area source where the emission rate varies over the surface
- The emission is from a large liquid area source such as an oxidation pond, where the emission varies with wind speed over the surface.

In summary use variable emission rate data when:

- There is evidence that shows how much and how often the emission rate will vary from the maximum potential emission rate as operational conditions change
- Assessing average ground-level concentrations for periods longer than the time that maximum emissions actually occur for
- Assessing the actual rather than the potential frequency of pollution events. When using variable emission rates, account for other factors that also vary with operational conditions, such as lowered efflux velocities and temperatures.

All assumptions made in using variable emissions should be clearly stated in the EIS and the modelling report.

With CALPUFF the modeller has the option of being able to make the emission as a series of puffs or a continuous release over the averaging period. AUSPLUME and AERMOD can only provide for a continuous emission.

4.4 Horizontal flues and stacks with rain caps

Stacks are modelled as point sources. Parameters that control plume rise, such as the initial vertical momentum and thermal buoyancy of the plume, are calculated from the characteristics of the stack emissions, in particular the temperature and exit velocity. If the exit of the stack is not pointed in a vertical direction, and unimpeded by any obstruction, the exit velocity used by the model will be different to the gas velocity within the stack itself.

Both horizontal flues and vertical flues with rain caps have little or no initial vertical velocity. Plume rise calculations in most models take into account both rise due to vertical momentum of the plume as it leaves the stack and the buoyancy of the plume. This may result in an over prediction of the plume rise, and resulting under prediction of ground-level concentrations, in these models.

This problem can be alleviated by modifying the source input parameters to minimize the effects of momentum while leaving the buoyant plume rise calculations unchanged. An approach to modelling this is to modify the source input parameters to minimize the effects of momentum while leaving the buoyant plume rise calculations unchanged. The approach is to reduce the stack gas exit velocity to either 0 m/s or to 0.001 m/s, and calculate an equivalent diameter so that the buoyant plume rise is properly calculated. To do this, the stack diameter is specified to the model such that the volume flow rate of the gas remains correct.

In the case of horizontal flues, there will be no stack tip downwash, so that option should be turned off for that case. In the case of vertical flues with rain caps, there will be frequent occurrences of stack tip downwash, however the effect of the stack tip downwash (reduction of the plume height by an amount up to three times the stack diameter) may be underestimated in the model. This can be corrected, somewhat conservatively, by turning off the stack tip downwash and lowering the specification of the stack height by three times the actual stack diameter (the maximum effect of stack tip downwash).

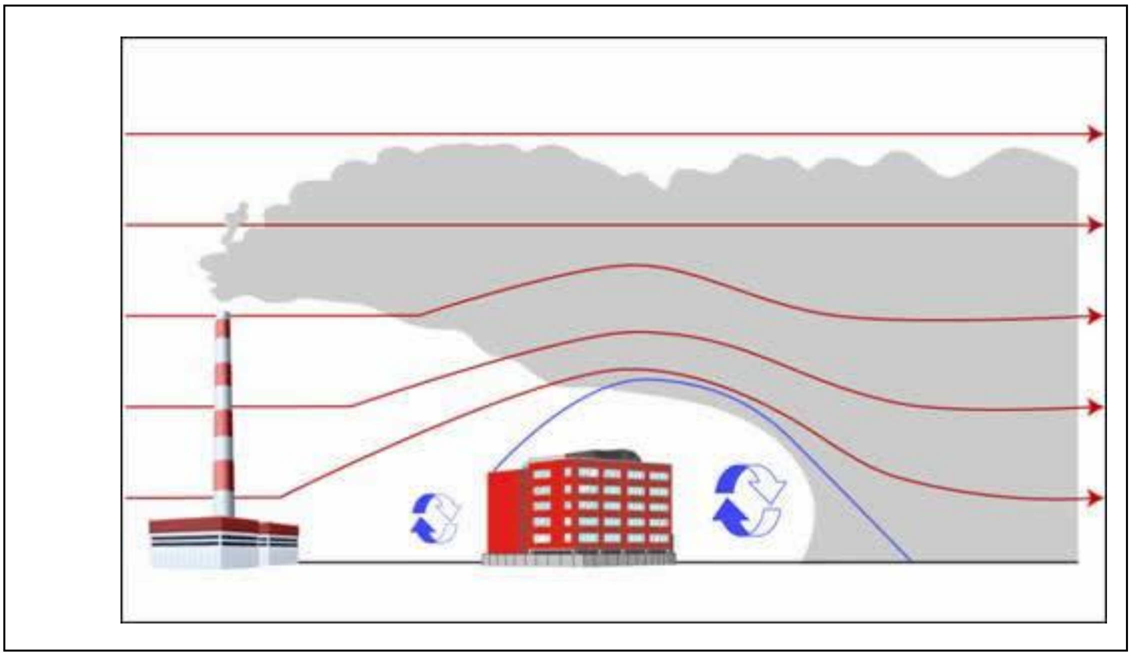
4.5 Buildings effects

Buildings and other structures near a relatively short stack can have a substantial effect on plume transport and dispersion, and on the resulting ground-level concentrations that are observed. There has long been a “rule of thumb” that a stack should be at least 2.5 times the height of adjacent buildings. Beyond that, much of what is known of the effects of buildings on plume transport and diffusion has been obtained from wind tunnel studies and field studies.

When the airflow meets a building (or other obstruction), it is forced up and over the building. On the lee side of the building, the flow separates, leaving a closed circulation containing lower wind speeds. Farther downwind, the air flows downward again. In addition, there is more shear and, as a result, more turbulence. This is the turbulent wake zone (see Figure 2).

If a plume gets caught in the cavity, very high concentrations can result. If the plume escapes the cavity, but remains in the turbulent wake, it may be carried downward and dispersed more rapidly by the turbulence. This can result in either higher or lower concentrations than would occur without the building, depending on whether the reduced height or increased turbulent diffusion has the greater effect.

The height to which the turbulent wake has a significant effect on the plume is generally considered to be about the building height plus 1.5 times the lesser of the building height or width. This results in a height of 2.5 building heights for cubic or squat buildings, and less for tall, slender buildings. Since it is considered good engineering practice to build stacks taller than adjacent buildings by this amount, this height came to be called “good engineering practice” (GEP) stack height.



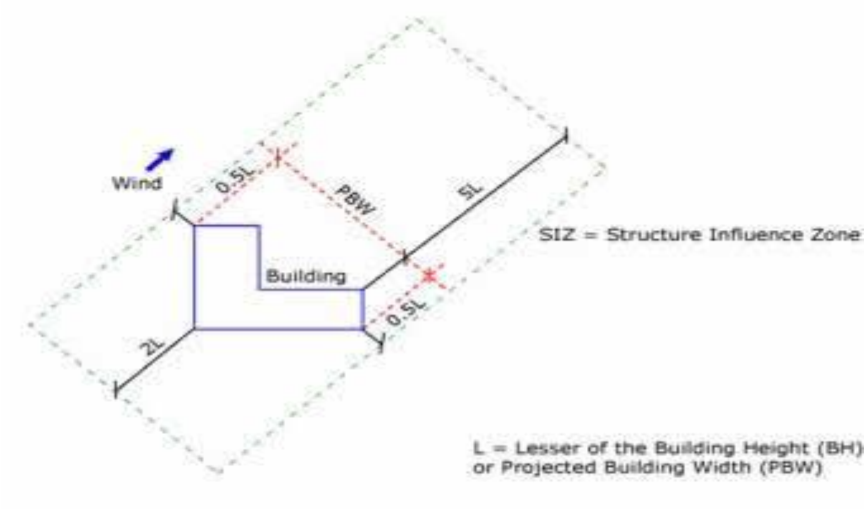
- **Figure 2 - The building downwash concept where the presence of buildings forms localized turbulent zones that can readily force pollutants down to ground level[1]**

Building downwash for point sources that are within the Area of Influence of a building should be considered. A building is considered sufficiently close to a stack to cause wake effects when the distance between the stack and the nearest part of the building is less than or equal to five (5) times the lesser of the building height or the projected width of the building.

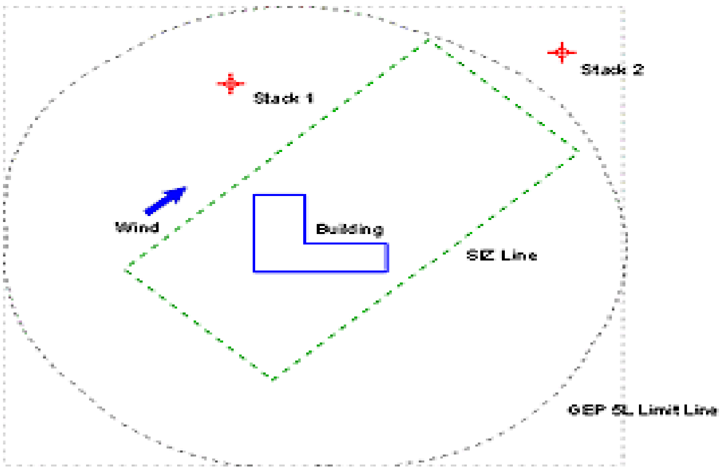
$$Distance_{stack-bldg} <= 5L$$

For point sources within the Area of Influence, building downwash information (direction-specific building heights and widths) should be included in your modelling project. Using BPIP-PRIME, you can compute these direction-specific building heights and widths. Building dimensions should be taken from a site layout plan or inputted into the model using an AUTOCAD dfx file. In all instances the co-ordinates of the building corners are required so it can be situated correctly on the model grid.

Structure Influence Zone (SIZ): For downwash analyses with direction-specific building dimensions, wake effects are assumed to occur if the stack is within a rectangle composed of two lines perpendicular to the wind direction, one at 5L downwind of the building and the other at 2L upwind of the building, and by two lines parallel to the wind direction, each at 0.5L away from each side of the building, as shown above. L is the lesser of the height or projected width. This rectangular area has been termed a Structure Influence Zone (SIZ). Any stack within the SIZ for any wind direction is potentially affected by wake effects for some wind direction or range of wind directions. See Figure 3 and Figure 4.



- **Figure 3 - GEP 5L and Structure Influence Zone (SIZ) Areas of Influence[1].**



- **Figure 4 - GEP 360° 5L and Structure Influence Zone (SIZ) Areas of Influence[1].**

The recommended screening and refined models all allow for the consideration of building downwash. SCREEN3 considers the effects of a single building while AUSPLUME, AEMOD and CALPUFF can consider the effects of complicated sites consisting of up to hundreds of buildings.

4.6 Geo-Spatial information

Geographical information requirements range from basic for screening analyses to advanced for refined modelling. SCREEN3 makes use of geographical information only for terrain data for complex or elevated terrain where it requires simply distance from source and height (elevation of the ground) in a straight-line. The AUSPLUME, AERMOD and CALPUFF models make use of complete three-dimensional geographic data with support for digital elevation model files and real-world spatial characterization of all model objects.

Recommendation 5: Geospatial data in particular terrain data needs to be developed and/or obtained for the Metro-Manila area to enable wind fields due to be terrain influences to be built into an AERMOD and CALPUFF meteorological data set. Without this information AERMOD and CALPUFF can not be used.

4.6.1 Model receptor grid

All dispersion models require the specification of the co-ordinates downwind from a source where the ground-level concentrations are to be recorded. The grid of receptors can be an evenly or unevenly spaced Cartesian or polar grid.

The extent of the grid should be chosen to include any regions of sensitive or important receptors such as residential areas, and should also be sufficiently large to capture peak downwind pollutant predictions. For sources emitting pollutants close to ground level, the maximum ground-level concentration will be close to the source. However, for stack sources the maximum ground-level concentration can be some distance away, and the model may have to be run more than once with increasing grid ranges to make sure the peak is captured.

Selecting the spacing between individual receptor points is a compromise between processing time and the required results resolution. If you double the number of receptors in your grid, the processing time will also double. However, if the spacing is too large, the peak ground-level concentration may fall between two receptor points and not be captured in the results file. Check that the grid spacing is small enough by running the model with increasingly smaller grid spacings near the location of the peak ground-level concentration, until halving the grid spacing effects a change in peak ground-level concentration of less than 10%. Irregularly spaced grids can be used to concentrate the number of receptors close to the location of the peak ground-level concentration.

Grid coordinates

Local coordinates encompass coordinate systems that are not based on a geographic standard. For example, a facility may reference its coordinate system based on a local set datum, such as a predefined benchmark. All site measurements can relate to this benchmark which can be defined as the origin of the local coordinate system with coordinates of 0,0 m. All facility buildings and sources could then be related spatially to this origin.

However, local coordinates do not indicate where in the actual world the site is located. For this reason, it is advantageous to consider a geographic coordinate system that can specify the location of any object anywhere in the world with precision. The coordinate system most commonly used for air dispersion modelling is the Universal Transverse Mercator (UTM) system. This coordinate system uses meters as its basic unit of measurement and allows for more precise definition of specific locations than latitude/longitude. If UTM is used, ensure all model objects (sources, buildings, receptors) are defined in the same horizontal datum.

Receptor flagpole heights

Unless otherwise specified by the user, models produce concentrations at ground level. It is standard practice that assessments of pollutant concentrations are conducted at ground level. Some modellers use concentrations that occur at the (approximate) height of a person (e.g. 1.8 m). In reality there is unlikely to be a significant gradient between the concentrations occurring at 1.8 m and at ground level. For the sake of consistency it is recommended that unless specific circumstances require otherwise, assessments are conducted at ground level.

Where tall buildings are near the source but are outside the Structure Influence Zone, flagpole receptor heights should be increase at this point on the grid to a height corresponding to the height of the building, where people could be exposed to the dispersing plume.

Size and range of grid

The approximate range applicability of plume models is:

- Receptors < 50 m from source – acknowledge large uncertainties and do not rely on model results
- Receptors 50 m − 100 m from source – use model results with some caution
- Receptors 100 m − 10 km from source – this is the usually accepted range of model applicability, although results for distances greater than about 5 km will lose accuracy due to wind shifts over that distance m(AUSPLUME, AERMOD and CALPUFF)
- Receptors >10 km from source – do not rely on plume model results; instead use a mesoscale or regional model which uses wind fields over the extent of the grid.

It should be noted that AERMOD and CALPUFF can be used as airshed models and can model much greater distances from the source than 10km as they use wind fields.

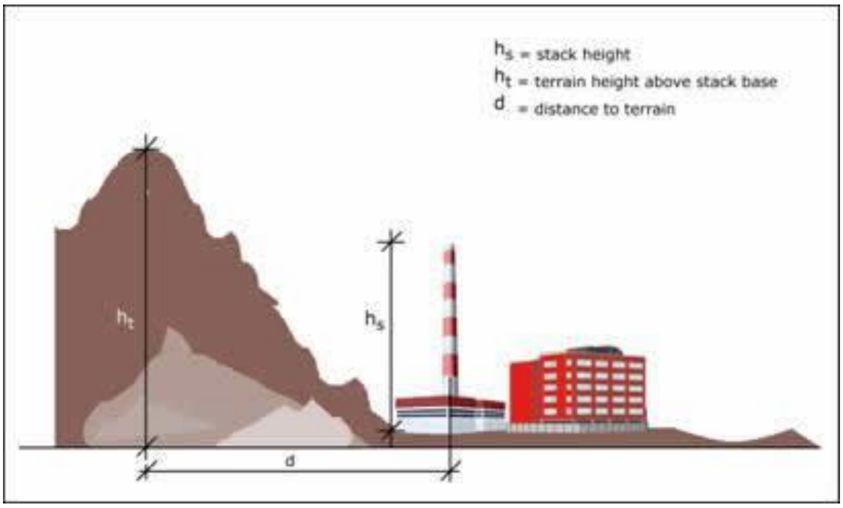
4.6.2 Terrain

Terrain concerns in short-range modelling

Terrain elevations can have a large impact on the air dispersion and deposition modelling results and therefore on the estimates of potential risk to human health and the environment. Terrain elevation is the elevation relative to the facility base elevation.

The models consider three different categories of terrain as follows:

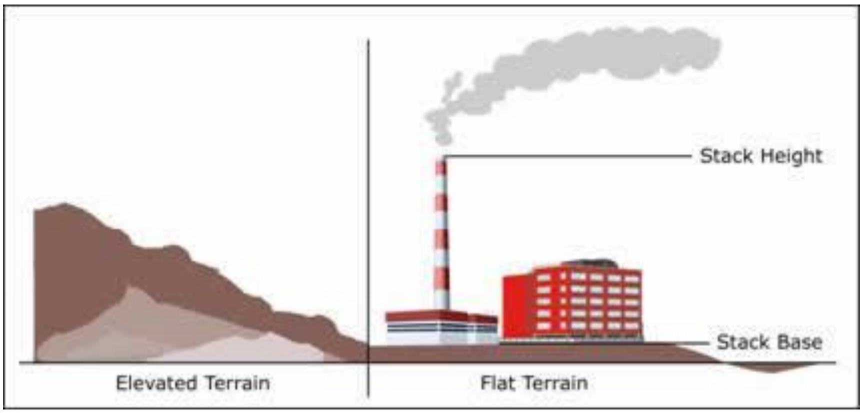
Complex Terrain: as illustrated in Figure 5, where terrain elevations for the surrounding area, defined as anywhere within 50 km from the stack, are above the top of the stack being evaluated in the air modelling analysis. AUSPLUME is not able to handle complex terrain above the height of the chimney, an alternative model such as AERMODor CALPUFF should be used in complex terrain situations.



▪ **Figure 5 - Sample complex terrain conditions**[1]

Simple Terrain: where terrain elevations for the surrounding area are not above the top of the stack being evaluated in the air modelling analysis. The "Simple" terrain can be divided into two categories:

- Simple Flat Terrain is used where terrain elevations are assumed not to exceed stack base elevation. If this option is used, then terrain height is considered to be 0.0 m.
- Simple Elevated Terrain, as illustrated in Figure 6 is used where terrain elevations exceed stack base but are below stack height.



▪ **Figure 6 – Sample elevated and flat terrain conditions**[1]

AUSPLUME can handle simple elevated terrain and the Egan half height option should be selected rather than the Modified Egan option.

Criteria for use of terrain data

Evaluation of the terrain within a given study area is the responsibility of the modeller. It should be remembered that complex terrain is any terrain within the study area that is above the source release height.

The appropriate terrain environment can be determined through the use of digital elevation data or other geographic data sources. Terrain data that are input into the models should be provided in electronic form. Digital Elevation Model data can be obtained from the makers of topographical maps for Philippines and from GIS models. Alternatively a topographic map of the area can be manually digitised across the cartesian grid selected for the model using SURFER or another appropriate GIS tool.

How accurate are results when terrain effects are significant?

The more complex the situation a model is required to simulate, the poorer its performance is likely to be. However, some models will handle complex terrain much more realistically than others. Plume model results must be treated with due caution when terrain effects are significant. There are three inherent limitations with plume models in complex terrain:

- Rudimentary treatment of terrain effects on plume lift
- No consideration of causal effects (i.e. the time it takes pollutants to travel to the terrain features), which means that only effects on terrain adjacent and close to the source should be considered
- The straight-line trajectory of the airflow.

4.7 Land use characterization

Land use plays an important role in air dispersion modelling from meteorological data processing to defining modelling characteristics such as urban or rural conditions. Land use data can be obtained from digital and paper land-use maps.

These maps will provide an indication into the dominant land use types within an area of study, such as industrial, agricultural, forested and others. This information can then be used to determine dominant dispersion conditions and estimate values for parameters such as surface roughness, albedo, and Bowen ratio.

- **Surface Roughness Length [m]:** The surface roughness length, also referred to surface roughness height, is a measure of the height of obstacles to the wind flow. Surface roughness affects the height above local ground level that a particle moves from the ambient air flow above the ground into a “captured” deposition region near the ground. This height is not equal to the physical dimensions of the obstacles, but is generally proportional to them. Table 1 lists typical values for a range of land-use types as a function of season.

The following method was proposed in the U.S. EPA OSW Human Health Risk Assessment Protocol to determine the surface roughness length for use with the ISC-PRIME/ISCST3 model at the application site:

1) Draw a radius of 3 Km from the center of the stack(s) on the site map.
2) Classify the areas within the radius according to the land use type categories listed in Table 5.1 (e.g., water surface, deciduous forest, etc.).
3) Calculate the wind rose directions from the 5 years of meteorological data to be used for the risk analysis.
4) Divide the area into 16 sectors of 22.5 degrees, corresponding to the wind rose directions.
5) Identify a representative surface roughness length for each sector, based on an area-weighted average of the land use within the sector.

6) Calculate the site surface roughness by computing an average surface roughness length weighted with the frequency of wind direction occurrence for each sector.

Table 1 Surface roughness lengths for typical surfaces[1]

Type of surface	Surface roughness length (m)
Urban	1.0–3.0
Coniferous forest	1.3
Cultivated land (summer)	0.2
Cultivated land (winter)	0.1
Grassland (summer)	0.1
Grassland (winter)	0.001
Water	0.0001

Source: Schnelle and Dey, 1999

- **Noon-Time Albedo**: Noon-time albedo is the fraction of the incoming solar radiation that is reflected from the ground when the sun is directly overhead. For practical purposes, the selection of a single value for noon-time albedo to process a complete year of meteorological data is desirable.
- **Bowen Ratio**: The Bowen ratio is a measure of the amount of moisture at the surface. The presence of moisture at the earth's surface alters the energy balance, which in turn alters the sensible heat flux and Monin-Obukhov length. Bowen ratio values vary depending on the surface wetness. Average moisture conditions would be the usual choice for selecting the Bowen ratio. If other conditions are used the regulatory agency should review the proposed Bowen ratio values used to pre-process the meteorological data.

The appropriate surface roughness show be selected by the modeller and reasons for setting the level of surface roughness stated in the modelling report.

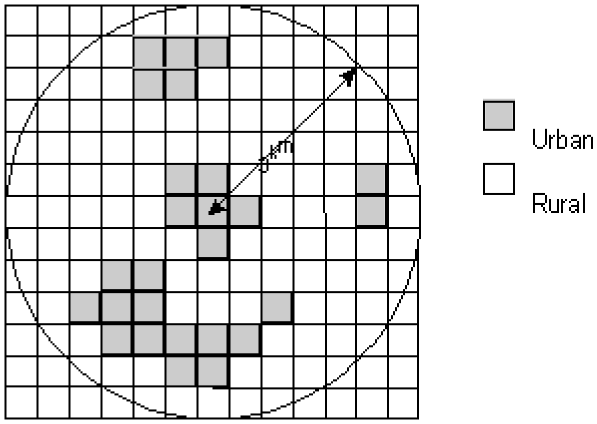
Defining urban and rural conditions

The classification of a site as urban or rural can be based on the Auer method specified in the EPA document Guideline on Air Quality Models (40 CFR Part 51, Appendix W). From the Auer's method, areas typically defined as Rural include:

- Residences with grass lawns and trees
- Large estates
- Metropolitan parks and golf courses
- Agricultural areas
- Undeveloped land
- Water surfaces

Auer defines an area as Urban if it has less than 35% vegetation coverage.

To verify if the area within the 3 km radius is predominantly rural or urban, overlay a grid on top of the circle and identify each square as primarily urban or rural. If more than 50 % of the total number of squares is urban than the area is classified as urban; otherwise the area is rural.



- **Figure 7 Example of determining whether to use Rural or Urban setting[1]**

4.8 Averaging times

Most dispersion models permit ground-level concentrations to be calculated for a range of averaging times. The minimum averaging time for AUSPLUME, AERMOD and CALPUFF is one hour, because the meteorological data are treated as hourly averages. However, AUSPLUME can go as low as a three minute averaging time as it uses the conversion factors set out in Appendix B to convert one hour average calculations into three minute averages. This is a regulatory function set up in the model to meet Victoran EPA requirements, and it is recommended that it is not used in the Philippines. All the models are able to provide a range of averaging times from one hour, 24-hour through to annual averages.

Where conversion to another averaging time is required the method and conversion factors specified in Appendix A should be used.

4.9 Use of regulatory options

The AUSPLUME, AERMOD and CALPUFF models contain several regulatory options, which are set by default, as well as non-regulatory options. Depending on the model, the non-regulatory options can include:

- No stack-tip downwash (NOSTD)
- Missing data processing routine (MSGPRO)
- Bypass the calms processing routine (NOCALM)
- Gradual plume rise (GRDRISM)
- No buoyancy-induced dispersion (NOBID)
- Air Toxics Options (TOXICS)
- By-pass date checking for non-sequential met data file (AERMOD)
- Flat terrain (FLAT) (AERMOD)

EMB requires that the use of any non-regulatory default option(s) be justified through a discussion in the modelling report.

It is advisable to discuss the use of any non-regulatory options in modelling assessments with EMB before submission of a refined modelling report.

5 Meteorological data

5.1 Sensitivity of models to meteorological data

Meteorological data is one of the most important inputs into any air dispersion model. Ground-level concentrations of contaminants are primarily controlled by two meteorological elements: wind direction and speed (for transport), and turbulence and mixing height of the lower boundary layer (for dispersion).

Steady-state Gaussian-plume models such as AUSPLUME and AERMOD require meteorological data from a single site. The data requirements can be met by three approaches, which are discussed in order below and are covered in Section 2 in the hierarchy approach to dispersion modelling. The use of each approach will strongly depend on the:

- Meteorological data available
- Purpose for which the model is being used
- Scale and significance of the potential effects of the discharge
- Accuracy of information and level of detail required by EMB.

The approach taken should match the scale and significance of the discharge being assessed, while making use of the best available meteorological data.

There has and still is a lack of meteorological data in the Philippines which has resulted in a lot of the dispersion modelling being undertaken using screening data sets. The aim is to move to Tier 3 and 4 dispersion modeling by:

- The development of regional meteorological data sets
- Making available meteorological data from ambient air monitoring stations operated by EMB that are located close to the site being assessed
- Installation of site specific meteorological stations and derivation of site specific meteorological data sets.

5.2 Screening meteorological data

As a first step and when worst-case events are of primary concern, it is generally recommended to use a standard screening meteorological data set as an initial air dispersion modelling assessment.

SCREEN3 provides 3 methods of defining meteorological conditions:

1) Full Meteorology: SCREEN will examine all six stability classes (five for urban sources) and their associated wind speeds. SCREEN examines a range of stability classes and wind speeds to identify the "worst case" meteorological conditions, i.e., the combination of wind speed and stability that results in the maximum ground level concentrations.

2) Single Stability Class: The modeller can select the stability class to be used (A through F). SCREEN will then examine a range of wind speeds for that stability class only.

3) Single Stability Class and Wind Speed: The modeller can select the stability class and input the 10-meter wind speed to be used. SCREEN will examine only that particular stability class and wind speed.

As discussed earlier AUSPLUME is supplied with a screening meteorological data set (METSAMP.MET). Screening meteorological data like METSAMP have been developed using standard combinations of wind speed, stability class and mixing heights, which should mimic the range of atmospheric conditions that are likely to occur in any given location. They provide a simple option to run the air dispersion model and can be applied in most locations. The maximum ground level concentration predicted using a screening data set is normally regarded as conservative. This means that it is likely the model over-predicts concentrations expected to occur in reality, assuming that other input data are of good quality. The results from a screening model are often termed ‘worst-case scenario’ impacts.

There are several limitations to these data. They can only model one-hour averages, not longer time-averaging periods such as eight hours, 24 hours or annual averages. This means that certain contaminants that have ambient guidelines for longer periods − such as PM10 (24 hours) − cannot be directly assessed using a screening data set.

Another limitation is that these data cannot provide an indication of how frequently an event might occur, what the spatial distribution of the impact is, nor average concentrations.

The screening meteorological data supplied with this model is only for one wind direction and the data needs to be manipulated using a spreadsheet to provide as a minimum 36 sectors at 10 degree intervals to allow the model as predict ground level concentrations for 360 degrees.

Screening meteorological data sets should therefore not be used for:

- Averaging periods longer than one hour
- PM10 sources that are likely to produce significant downwind concentrations
- Frequency assessment of pollution events
- Airshed sources.

In summary screening meteorological data sets should only be used to gain a ‘first cut’ estimate of the magnitude of the maximum ground-level concentration for a particular source. When a screening data set is used, the modeller must ensure it contains mixing heights and stability classes which realistically represent the location being modelled. To estimate the ‘worst-case’ scenario, all other model inputs, such as emission rates, must be selected and shown to produce ‘conservative’ results.

5.3 Regional meteorological data sets

When screening meteorological data cannot be used, it may be appropriate to use in the first instance regional meteorological data sets for modelling, especially if site specific data is not available. These situations include those when a screening data set does not:

- Provide sufficient accuracy

- Meet the criteria of the ambient air quality guidelines in terms of averaging times
- Suit the source or type of pollutant being modelled (e.g. PM10 from a large coal-fired boiler).

Recommendation 6: EMB has to prepare a regional meteorological data sets for use in Tier 3 modelling in two formats:

- **Regional pre-processed model ready data for AUSPLUME using meteorological data collected by the ambient air monitoring network for Metro-Manila.**
- **Regional pre-processed model ready data using a mesoscale metrological model such as MM5 or TAPM for AUSPLUME. This data can be processed using AERMET or CALMET to produce an AERMOD and CALPUFF data sets.**

The above data sets will be available online. The availability of standard meteorological data will reduce inconsistencies in data quality and provide a more consistent approach to dispersion modelling.

5.3.1 Development of regional meteorological data sets

In order to develop regional meteorological data sets, there are two data sources potentially available:

1) The meteorological data recorded by the EMB ambient air monitoring network;

2) The use of a mesoscale meteorological model developed by PAGASA or one of the universities.

EMB Web Page also reports that all network components are operational and one year ago reported:

"There are eight stations of the ten station network that are complete and operational. All eight stations are currently online and measure criteria and non-criteria pollutants. The criteria pollutants are: particulate matter (PM10), sulfur dioxide, carbon monoxide, nitrogen dioxide, ozone and lead. The non-criteria pollutants are benzene, toluene and xylene. The network measures also meteorological data which include, wind direction, vertical wind speed, wind speed, temperature, relative humidity, net radiation, barometric pressure, solar radiation (400-1100 nm) and UV radiation (295-385 nm)".

"The eight monitoring (stations) are located in Ateneo- Katipunan, Quezon City, Clark Air Base-Pampanga, Los Baños, Laguna, NAMRIA- Fort Bonifacio, PUP-Sta Mesa, Cavite, Batangas and Valenzuela."

The meteorological parameters being recorded by these stations would appear to be sufficient to enable 'real time' meteorological data sets to be developed for each of these locations and for the region.

Further work is required to interrogate the data recorded at these stations as to there completeness and to develop the meteorological datasets using the methods and routines specified in On-site Meteorological Program Guidance for Regulatory Modelling Applications (US EPA, 1987) and Part 51, Guideline on Air Quality Models (US EPA, 1999). This document provides details on site location, recording mechanisms, data communication, sampling rates, system accuracies, data handling, quality control and treatment of missing data. It is recommended that this guidance be adopted as best practice for the collection and processing of meteorological data for use in dispersion modelling applications.

Recommendation 7: That EMB needs to develop meteorological datasets that can be used for dispersion modelling from the meteorological data recoded by their ambient air monitoring network. The recorded data needs t be interrogated as to completeness and processed in local specific and a regional set.

The use of a mesoscale/prognostic approach to developing a regional meteorological data set is an alternate method. Prognostic models do not need local meteorological observations to run, so can simulate the meteorology of regions where few data are available. This lack of data is in issue in the Philippines. Prognostic models can take advantage of local meteorological data by the process of meteorological data assimilation. The use of a mesoscale or prognostic model to develop regional data sets for the use in dispersion modelling should be undertaken by an appropriate qualified metrologist or dispersion modeller.

5.4 Site-specific data sets

If a suitable ready-made meteorological data set is not available or is not applicable to the site in question, one needs to be developed. Provided it is of good quality, on-site data are often the preferred source of meteorological input data even if other nearby sets are available. A distinct advantage of having on-site data is that they can also be used for dispersion model valuation studies.

The following sections provide current recommended practices for developing a site specific meteorological data set. It is recommended that if the data are to be used as part of an AEE, they are put through a thorough quality assurance process and/or peer reviewed before use. The collection of site-specific meteorological data has been fully covered in the documents *On-site Meteorological Program Guidance for Regulatory Modelling Applications* (US EPA, 1987) and Part 51, *Guideline on Air Quality Models* (US EPA, 1999). The former provides details on site location, recording mechanisms, data communication, sampling rates, system accuracies, data handling, quality control and treatment of missing data. It is recommended that this guidance be adopted as best practice for the collection and processing of meteorological data for use in dispersion modelling applications.

5.4.1 Data collected on site

A meteorological station should be located away from the influences of obstructions such as buildings and trees to ensure that the general state of the environment (wind direction and temperature) is best represented. It is recommended that you use a 10 m high mast for measuring wind direction and speed and temperature differentials. However, where the mast is located in good free-flow conditions and there are height restrictions from local council bylaws, a 6m high mast can be used. For major industrial sources with tall stacks, or a site within a complex terrain environment, higher monitoring masts (30 m and higher) are recommended to adequately monitor lower boundary-layer wind and temperature profiles.

On-site data should be reduced to hourly averages for all parameters. To develop a meteorological data set for air dispersion modelling the following parameters need to be monitored from the site:

- Temperature
- Temperature difference (between 1.5 m and 10 m or higher)
- Relative humidity

- Wind speed
- Wind direction
- Solar radiation.

While all the above variables provide valuable information for modelling, the most important variables are wind speed and direction, and temperature.

The data collected may need to be supplemented with the following off-site data:

- Hourly cloud cover and height for the region
- Twice-daily upper air temperature, relative humidity, and wind speed and direction from the closest upper air radiosonde station.

When developing a meteorological data set, the representativeness of the data set must be assessed, and demonstrated, in terms of climatic means and extremes. This can essentially be established in two ways: by undertaking long-term (three to five year) monitoring of on-site data collection, or by establishing correlations between on-site data, climatic averages and regional extremes.

The sources of all of the data used including cloud data and upper air data must be documented. The proponent also needs to describe why the site chosen is representative for the modelling application. This would include a description of any topographic impacts or impacts from obstructions (trees, buildings etc.) on the wind monitor. Information on the heights that the wind is measured is also required. The time period of the measurements along with the data completeness and the percentage of calm winds should be reported.

Wind roses showing the wind speed and directions should be provided with the modelling assessment. If wind direction dependent land use was used in deriving the final meteorological file, the selection of the land use should be described.

5.4.2 Data from locations removed from but close to the site

As a rule, site-specific data is always preferred when developing a meteorological data profile for a specific source. However, sometimes this is not possible or other suitable surface meteorological data from other local sources may be available. For simple single-station plume modelling, off-site data should only be used if the nearby site has similar topographic characteristics which are likely to result in similar meteorological conditions for the site concerned. For example, when both sites are located in the same valley system, or are in close proximity along a coastline. The representativeness of off-site data must be established before being used in any dispersion study.

5.5 Where to get raw data from

The three principal sources of meteorological data are:

- US National Climatic Data Center which includes data from US military bases located in the Philippines
- The Philippines Atmospheric, Geophysical & Astronomical Services Administration (PAGASA)
- EMB, which operate ambient air quality monitoring stations

Another potential source of data is the International Rice Research Institute (IRRI).

6 Background ambient air data

6.1 Accounting for background concentrations

While there is usually a case for assessing the effects of a particular discharge, people are more interested in the overall end result − the cumulative effect. The CAA 1991 requires that background ambient air concentrations are in included in determining the level of impact for a proposed new plant or an extension to an existing plant.

This means that modelling results must be added to current background concentrations discharged by other sources.

Recommendation 8: Modelling assessments must take into account the potential cumulative effects caused by the addition of the discharge being modelled to the current background concentrations.

6.2 When local background air quality data is available

Having suitable data on background concentrations is an ideal, but uncommon, circumstance. However, the general rule is that anything is better than nothing, and it is worth obtaining whatever data are available from a monitoring site as close as possible to the discharge. This includes:

- EMB's ambient air monitoring network
- Short term ambient air monitoring data collected form the proposed site (usually less than three months in duration).
- Longer term site data (one year or more).

The type, quality and representativeness of these data sets vary enormously, and it is very important to understand what has been measured. In conjunction with the air quality monitoring data, it is also important to get hold of any meteorological monitoring from the site as well. This information can help to determine whether the peak background concentrations occur under the same conditions as the peak modelled predictions.

When available, use locally recorded air quality data to assess background levels. The use of background data for total impact assessments should be accompanied by a discussion of its applicability for the intended purpose. If there is any doubt as to the validity of the information, it should not be used without specific justification. Meteorological data from the monitoring site should also be examined when assessing the background monitoring results.

Recommendation 9: EMB to maintain the ambient air monitoring network that has been established in the Metro-Manila region and to provide access to the collected data, via reports so that background ambient air concentrations be included in modelling assessments.

6.3 When local background air quality data is not available

In all cases, an assessment of cumulative (background plus plant) impacts is required, so background concentrations need to be estimated. Options for estimating background concentrations are discussed below.

a) Model other sources

In some cases it is viable to explicitly model the likely cumulative ground-level concentrations caused by other sources in the area. For instance, if the issue is how a particular plant's emissions affect an area that only has one or two other sources (even if these are complex, such as a roadway), then the modelling can include these sources.

b) Compare the location with somewhere similar

If the area does not have significant large sources, and does not have any complex geographical or meteorological features, then it can be assumed that the air quality will be similar to another area of similar population density, emission sources and meteorology. This method requires that such an area can be identified, and that monitoring data are available.

c) Make a worst-case assumption

In the absence of any of the above it might be necessary to simply 'guess' the existing air quality. The safest guess is to assume a concentration that is at the upper end of what might be feasible, based on what is monitored in, say, in Quezon or Pasig City. The assumptions and sources used to derive this 'worst-case' assumption needs to be included in the modelling report.

d) Start a new monitoring program

If all else fails, or if the issue is likely to be of significant importance, start a new monitoring program as soon as possible. This need not be expensive, as useful information can be gained from relatively short-term surveys, or from passive monitoring.

6.4 How to incorporate background data

Once background air quality data and model results are available, adding the two together to provide an estimate of the cumulative impact of the discharge provides the most conservative result. However, there are a number of issues with this approach, and in some circumstances a different method is preferable.

a) Spatial co-incidence problems

It is often difficult to know whether the background data is representative of the point at which the modelled peak occurs. In general they will not be, leading to an overestimate of the cumulative impact. However, provided the overestimate is within the evaluation criteria the impacts of the discharge are likely to be minor.

b) Time co-incidence problems

Both the modelled and the background concentrations vary with time of day. In most cases the peak due to a point source emission does not occur at the same time as the background peak. High background concentrations therefore almost always occur in calm to light wind conditions, when plumes from point sources may not reach the ground. On the other hand, point source peaks usually occur in:

- Highly unstable daytime conditions
- Stable, light-wind night-time conditions or
- The transition from night to morning, when fumigation may occur.

Without going to relatively complicated peak to mean ratio calculations the estimation of the cumulative impact by combining the highest 98 percentile with the mean background ambient air concentration should suffice. If this routine shows that the national ambient air quality guidelines will be exceeded, some form of peak to mean ratio should be applied. But the key limiter here is on the validity and length of time the ambient air data set is measured over.

7 Model Limitations and Uncertainty

7.1 Model Limitations

7.1.1 SCREEN3

SCREEN3 is a screening model that can only model one source from a site. It has worst-case screening meteorological data and can not be used on real time meteorological data.

7.1.2 AUSPLUME

AUSPLUME doe not handle complex terrain, that is terrain above the height of the discharged plume and alternative model that can handle complex terrain such AERMODand CALPUFF should be considered being used to conduct the modelling.

AUSPLUME is a steady-state plume model. For the purpose of calculating concentrations, the plume is assumed to travel in a straight line without significant changes in stability as the plume travels from the source to a receptor. At distances on the order of tens of kilometres downwind, changes in stability and wind are likely to cause the accuracy to deteriorate. For this reason, AUSPLUME should not be used for modelling at receptors beyond 10 kilometres. AUSPLUME may also be inappropriate for some near-field modelling in cases where the wind field is very complex due to terrain or a nearby shoreline.

7.1.3 ARMOD

AERMOD is a steady-state plume model. For the purpose of calculating concentrations, the plume is assumed to travel in a straight line without significant changes in stability as the plume travels from the source to a receptor. At distances on the order of tens of kilometres downwind, changes in stability and wind are likely to cause the accuracy to deteriorate. For this reason, AERMOD should not be used for modelling at receptors beyond 50 kilometres. AERMOD may also be inappropriate for some near-field modelling in cases where the wind field is very complex due to terrain or a nearby shoreline.

AERMOD does not treat the effects of shoreline fumigation. Shoreline fumigation may occur along the shore of the ocean or large lake. When the land is warmer than the water, a sea breeze forms as the warmer, lighter air inland rises. As the stable air from over the water moves inland, it is heated from below, resulting in a turbulent boundary layer of air that rises with downwind distance from the shoreline. The plume from a stack source located at the shoreline may intersect the turbulent layer and be rapidly mixed to the ground, a process called “fumigation,” resulting in high concentrations. In these and other situations, the use of alternative models may be desired.

7.1.4 CALPUFF

CALPUFF is a puff dispersion model and can a handle a range of situations the above models can not handle including dispersion over water. It is a very sophisticated and therefore very complex model to use and interpret data from. Data input errors are issue if the modeller is not careful and there are some functions in the model when used need careful interpretation. CALMET data supplied by third parties can not be easily interrogated.

CALPUFF model should be only used by experienced modellers who have received appropriate training in the use of the model.

7.2 Accounting for and reporting of model error and uncertainty

One of the most common criticisms of dispersion modelling is, “It’s not at all accurate − it’s only a model”. To avoid such criticisms it is important to follow some simple principals, as listed in below.

Design all modelling studies to be as accurate as possible for the purpose of the study.

Allow the accuracy of the modelling study to be easily assessed by:

- stating the objectives of the study
- demonstrating that the model inputs are as correct as possible
- knowing and stating the model performance limitations
- demonstrating (via the methodology) that the modelling process has been conducted appropriately
- including any validating information from monitoring that might be available.

If corners are cut on any of these, the results can be at best meaningless, and at worst dangerous, especially if they are used to justify an important decision. There are three main general sources of error and uncertainty in dispersion modelling:

- inaccurate input data
- inappropriate use of the model (or expecting too much from it)
- poor performance of the model itself.

The total uncertainty contained in the model results is the cumulative effect of these sources.

7.2.1 Input data uncertainty

Any model is only as good as the input data. There are three sets of data needed for dispersion modelling:

a) source, or emissions characteristics,

b) meteorological data, and

c) terrain and local features data

Steps to overcome this source data input uncertainty include:

- Clearly state the value and the origin of the source characteristics data that have been put into the model.
- Include a copy of the model input file as an (electronic) appendix to the report.
- Justify your choice of a particular value of a parameter, or run the model with a range of possible input values.
- Preferentially use measured source characteristic values over estimated rates or emission factors.
- If using calculated source characteristic values, clearly state the method used to calculate the value. Provide detailed calculations in an appendix to the main report and explain potential uncertainty with the values.

- Pay particular attention to emission rate data by:
  - using a rate that is sufficiently large to cover the worst-case discharge of concern
  - ensuring the period the emission lasts for matches the averaging period of the relevant assessment criteria.
- Provide a sensitivity analysis of model results to variation in source characteristics. This can be done by running the model with the two extreme values of a particular characteristic (e.g. low and high efflux velocities).
- Facilitate an independent review of the source data and avoid requests for further information by reporting all sources of data and assumptions made.

Lack of appropriate meteorological information is often the single most important limiting factor in modelling accuracy. It is also the most subjective in deciding just how much data are needed, from which location and how accurate they must be.

The ideal is to have at least three year of data, with at least hourly resolution, at the site of interest (usually within a few hundred metres) with the minimum being one year of data. The minimum measurement requirements are for wind speed and direction, but some method of estimating stability and mixing height is also required as an input for steady-state modelling.

Steps to overcome this meteorological data uncertainty include:

- Clearly state the origin of the meteorological data that have been put into the model.
- Minimise the meteorological input data uncertainty by following (as far as practicable) the recommendations made in this document in section 5.
- Facilitate an independent review of the meteorological data by reporting all sources of data, assumptions made and any guideline recommendations not followed.
- Assess the sensitivity of the model's prediction of the magnitude of the maximum ground-level concentration to meteorological input data. Do this by running the model with data from a number of years, or data from a site with similar climate and meteorology. A comparison with results obtained using screening data can also be useful.
- Include a copy of the meteorological data file(s) used as an (electronic) appendix to the report.

Information about the terrain features surrounding the site that affect dispersion and plume behaviour. Determining the required accuracy for terrain and other local features is quite subjective. In many cases the decision is determined by what is available rather than what is required.

Steps to reduce the reviewers/readers uncertainty include:

- Clearly state the origin of the terrain data that have been put into the model.
- Justify your choice of a particular value of a parameter, or run the model with a range of possible input values.

- Quantify the influence of terrain information on the model results in any particular application by performing an analysis of the sensitivity of the model results to each terrain parameter (section 6.2.4c).

7.2.2 Model performance

After input data uncertainty, the fundamental limitation for dispersion model accuracy is the way the model works. This includes the structure, physics and chemistry, and the way these are all parameterised and computed.

In theory, it should be possible to evaluate any model's performance by a formalised evaluation scheme, whereby it is compared with actual monitoring results (with all other things being equal − emissions rates, meteorology and terrain).

AUSPLUME has been validated by the Victorian EPA, and ARMOD and CALPUFF by the USEPA.

This validation is one of the primary reasons for selecting these models as approved by EMB for use in the Philippines under the CAA.

7.3 Misapplication of models

A common, but largely avoidable, source of modelling uncertainty is a model being used inappropriately. Some cases of this are:

- Using a Gaussian-plume model to predict effects on a steep hill above plume centre-line
- Ignoring building downwash for a short stack on a large building
- Using the output from screening modelling to produce a percentage exceedance (yes it has been done!)
- Using a default meteorological data set that comes with the model (and is from the other side of the world to Philippines).
- Having the wrong default values in the user settings (such as a 0.1 m roughness length over an urban area when it should be 1 m or even 2 m)
- Editing input data sets (particularly meteorological files) to remove conditions that lead to high concentrations
- Assigning too much accuracy to the model output (e.g. "The modelled peak is 348, which is less than the 350 guideline, so its fine").

There are no specific recommendations to avoid these problems, except to approach all modelling results with caution and to seek further information where anything is not clear.

7.4 Analysis and interpretation of model results

Once the modelling has been carried out, the results should be analysed to ensure they are believable – at this stage there may still be errors in the model configuration that have not been found (or could not have been predicted). Although the user is often guided by experience, there are a several checks that should always be carried out.

Are the highest concentrations in the right location?

- Expect peak concentrations very near the source for low-level emissions.
- Expect peaks further downwind of tall stacks.

- Expect peaks on terrain features as plumes impinge on them (although these may not be realistic in a Gaussian-plume model if the hill is too distant).

Are the highest concentrations consistent with the meteorological conditions?

- Expect peak concentrations from tall stacks during convective/fumigation conditions.
- Expect peaks from low-level emissions during stable conditions (e.g. night time).
- Check how the concentrations vary with wind speed, taking care with calm periods.
- Check whether the highest-ranked concentrations occur at the same time, but at different locations (receptors), and are therefore occurring under the same meteorological conditions.
- Group the highest-ranked concentrations according to location, time of day and meteorological conditions to determine whether they are clustered into pollution 'events'.

Do the highest concentrations coincide with the maximum emissions?

- If the emissions are time-dependent, look at the relationship between times of maximum emissions and times of highest concentrations.

Are the highest (and lowest) concentrations consistent with air quality observations?

•If air quality observations are available, and the model results provide a good match at the monitoring site, then confidence in the model to simulate pollution levels elsewhere is increased.

When using non-steady-state meteorology: are the important conditions simulated well by the meteorological model?

- Quantify the extent to which the dispersion model results are affected by meteorological model performance
- If high concentrations are expected during, say, sea-breeze conditions, slow valley-drainage flows or pooling of still air, check that the meteorological model gives a realistic representation of such conditions.
- Check whether peak concentrations occur during these conditions, both in the model and in the observations (if any).
- If the model performs poorly in these conditions, take steps to improve the meteorological simulation (through changes in the meteorological model configuration).

These considerations will help the interpretation and provide information that can be used to validate the model results. They will also help to determine the relationships between pollution levels, meteorology and emissions. Finally, if required, the above considerations will enable predictions of what would happen under alternative scenarios.

7.5 EIS Report requirements

The impact assessment report based on dispersion modelling must contain the information specified below.

Site plan

- Layout of the site clearly showing all unit operations.
- All emission sources clearly identified.
- Plant boundary.
- Sensitive receptors (e.g. nearest residences).
- Topography.

A description of the activities carried out on the site

- A process flow diagram clearly showing all unit operations carried out on the premises.
- A detailed discussion of all unit operations carried out on the site, including all possible operational variability.
- A detailed list of all process inputs and outputs.
- Plans, process flow diagrams and descriptions that clearly identify and explain all pollution control equipment and techniques for all processes on the premises.
- A description of all aspects of the air emission control system, with particular regard to any fugitive emission capture systems (e.g. hooding, ducting), treatment systems (e.g. scrubbers, bag filters) and discharge systems (e.g. stacks).
- The operational parameters of all emission sources, including all operational variability, i.e. location, release type (stack, volume or area) and release parameters (e.g. stack height, stack diameter, exhaust velocity, temperature, emission concentration and rate).

A description of meteorological data

- A detailed discussion of the prevailing dispersion meteorology at the proposed site. The report should typically include wind rose diagrams; an analysis of wind speed, wind direction, stability class, ambient temperature and mixing height; and joint frequency distributions of wind speed and wind direction as a function of stability class.
- Demonstration that the site-representative data adequately describe the expected meteorological patterns at the site under investigation (e.g. wind speed, wind direction, ambient temperature, atmospheric stability class, inversion conditions and katabatic drift).
- A description of the techniques used to prepare the meteorological data into a format for use in the dispersion modelling.
- A quality assurance and quality control analysis of the meteorological data used in the dispersion modelling. Provide and discuss any relevant results of this analysis.
- The meteorological data used in the dispersion modelling supplied in a Microsoft Windows compatible format.

Emission inventory

- A detailed discussion of the methodology used to calculate the expected pollutant emission rates for each source.
- All supporting reports of source emission tests.
- Methodologies used to sample and analyse for each of the pollutants considered

- Detailed calculations of pollutant emission rates for each source.
- A table showing all release parameters of stack and fugitive sources (e.g. temperature, exit velocity, stack dimensions, and emission concentrations and rates).
- A table showing all pollutant emission concentrations with a comparison of the emission concentrations against the relevant requirements of CAA and IRR.

Background concentrations

- Methods used to sample and analyse for each of the pollutants considered.
- A detailed discussion of the methodology used to calculate the background concentrations for each pollutant.
- Tables summarising the ambient monitoring data.

Dispersion modelling

- A detailed discussion and justification of all parameters used in the dispersion modelling and the manner in which topography, building wake effects and other site-specific peculiarities that may affect plume dispersion have been treated.
- Detailed discussion on assumptions made and where non-regulatory defaults were used.
- A detailed discussion of air quality impacts for all relevant pollutants, based on predicted ground level concentrations at the plant boundary and beyond, and at all sensitive receptors.
- Ground-level concentrations, hazard index and risk isopleths (contours) and tables summarising the predicted concentrations of all relevant pollutants at sensitive receptors.
- All input, output and meteorological files used in the dispersion modelling supplied in hard copy and in a Microsoft Windows-compatible format.

Site-specific emission limits

- All calculations and data relating to the derivation of site-specific emission limits.

8 Bibliography

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Appendix A: Approved Dispersion Models

A.1 Screen Overview

The SCREEN model was developed to provide an easy-to-use method of obtaining pollutant concentration estimates. These estimates are based on the document "Screening Procedures for Estimating The Air Quality Impact of Stationary Sources".

SCREEN3, version 3.0 of the SCREEN model, can perform all the single source short-term calculations in the EPA screening procedures document, 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.
- Determining plume rise for flare releases.

EPA's SCREEN3 model can also:

- Incorporate the effects of simple elevated terrain (i.e., terrain not above stack top) on maximum concentrations.
- Estimate 24-hour average concentrations due to plume impaction in complex terrain (i.e., terrain above stack top) using the VALLEY model 24-hour screening procedure.
- Model simple area sources using a numerical integration approach.
- Calculate the maximum concentration at any number of user-specified distances in flat or elevated simple terrain, including distances out to 100 km for long-range transport.
- Examine a full range of meteorological conditions, including all stability classes and wind speeds to find maximum impacts.
- Include the effects of buoyancy-induced dispersion (BID).
- Explicitly calculate the effects of multiple reflections of the plume off the elevated inversion and off the ground when calculating concentrations under limited mixing conditions.

To perform a modelling study using SCREEN3, data for the following input requirements must be supplied:

- Source Type (Point, Flare, Area or Volume)
- Physical Source and Emissions Characteristics. For example, a point source requires:
  - Emission Rate
  - Stack Height
  - Stack Inside Diameter
  - Stack Gas Exit Velocity
  - Stack Gas Exit Temperature
  - Ambient Air Temperature

- Receptor Height Above Ground

- Meteorology: SCREEN3 can consider all conditions, or a specific stability class and wind speed can be provided.
- Building Downwash: If this option is used then building dimensions (height, length and width) must be specified.
- Terrain: SCREEN3 support flat, elevated and complex terrain. If elevated or complex terrain is used, distance and terrain heights must be provided.
- Fumigation: SCREEN3 supports shoreline fumigation. If used, distance to shoreline must be provided.

A.2 AUSPLUME Overview

The AUSPLUME dispersion model is a steady-state Gaussian plume model, which can be used to assess pollutant concentrations, and/or deposition fluxes from a wide variety of sources associated with an industrial source complex. The AUSPLUME dispersion model from the Victorian EPA was designed to support the Vic EPA's regulatory modelling options, as specified in the SEPP.

The PRIME algorithms have been integrated into the AUSPLUME (Version 6) model.

To be able to run the AUSPLUME model, you must first perform building downwash analysis using BPIP-PRIME (Building Profile Input Program). For more information on building downwash please refer to Section 4.6 - Building Impacts.

Some of the AUSPLUME modelling capabilities are:

- May be used to model primary pollutants and continuous releases of toxic and hazardous pollutants.
- Can handle multiple sources, including point, volume, area, and open pit source types. Line sources may also be modelled as a string of volume sources or as elongated area sources.
- Source emission rates can be treated as constant or may be varied by month, season, hour-of-day, or other optional periods of variation. These variable emission rate factors may be specified for a single source or for a group of sources.
- The model can account for the effects of aerodynamic downwash due to nearby buildings on point source emissions.
- The model contains algorithms for modelling the effects of settling and removal (through dry deposition) of large particulates and for modelling the effects of precipitation scavenging for gases or particulates.
- Receptor locations can be specified as gridded and/or discrete receptors in a Cartesian or polar coordinate system.
- AUSPLUME incorporates the Egan Half Heights and Modified Egan algorithms for handling complex terrain.
- Model used hourly meteorological data to account for the atmospheric conditions that affect the distribution of air pollution impacts on the modelling area.
- Results can be output for concentration, total deposition flux, dry deposition flux, and/or wet deposition flux.

A.3 AERMOD

The AERMIC (American Meteorological Society/EPA Regulatory Model Improvement Committee) Regulatory Model, AERMOD, was specially designed to support the U.S. EPA's regulatory modelling programs. AERMOD is the next-generation air dispersion model that incorporates concepts such as planetary boundary layer theory and advanced methods for handling complex terrain. AERMOD was developed to replace the Industrial Source Complex Model-Short Term (ISCST3) as U.S. EPA's preferred model for most small scale regulatory applications. The latest versions of AERMOD also incorporate the Plume Rise Model Enhancements (PRIME) building downwash algorithms, which provide a more realistic handling of downwash effects than previous approaches.

The Plume Rise Model Enhancements (PRIME) model was designed to incorporate two fundamental features associated with building downwash:

1) Enhanced plume dispersion coefficients due to the turbulent wake.

2) Reduced plume rise caused by a combination of the descending streamlines in the lee of the building and the increased entrainment in the wake.

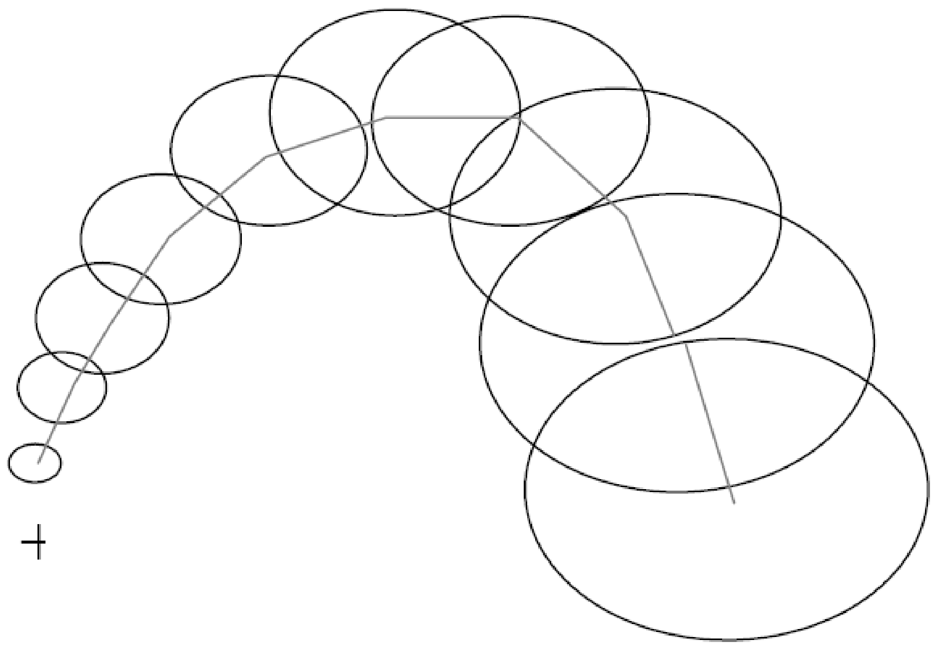
AERMOD contains basically the same options as the ISCST3 model with a few exceptions, which are described below:

- Currently, the model only calculates concentration values. Dry and wet deposition algorithms were not implemented yet at the time this document was written.
- AERMOD requires two types of meteorological data files, a file containing surface scalar parameters and a file containing vertical profiles. These two files are produced by the U.S. EPA AERMET meteorological pre-processor program.
- For applications involving elevated terrain, the user must also input a hill height scale along with the receptor elevation. The U.S. EPA AERMAP terrain pre-processing program can be used to generate hill height scales as well as terrain elevations for all receptor locations.

The options AERMOD has in common with ISCST3 and ISC-PRIME are described in the next section.

A.4 CALPUFF

CALPUFF (a puff model) has recently been accepted by the US EPA as a guideline model to be used in all regulatory applications involving the long-range (>50km) transport of pollutants. It can also be used on a case-by-case basis in situations involving complex flow and non-steady-state cases from fence-line impacts to 50 km. CALPUFF is a multi-layer, multi-species non-steady-state Gaussian puff dispersion model which is able to simulate the effects of time- and space-varying meteorological conditions on pollutant transport (Scire, 2000a). Its puff-based formulation is described in Figure A1. This enables the model to account for a variety of effects such as spatial variability of meteorological conditions, causality effects, dry deposition and dispersion over a variety of spatially varying land surfaces, plume fumigation, low wind-speed dispersion, pollutant transformation and wet removal. CALPUFF has various algorithms for parameterising dispersion processes, including the use of turbulence.



+ Release point

Figure A1 Graphical representation of Puff modelling approach

The meteorological data for a full CALPUFF run are provided by CALMET, its meteorological pre-processor. This is described in section 5.3.1. However, it is possible to overcome some of the limitations of the plume model without carrying out a full CALPUFF run, as CALPUFF may also be driven by meteorological data from a single site in the same form as the data for AUSPLUME or ISCST3. This overcomes some of the following limitations of the Gaussian-plume formulation: - the effects of causality will be simulated (i.e. no spot light effect), - the previous hour's emissions are included, -calm and low wind speeds will be treated more realistically.

Appendix B: Conversion Factors for Averaging Times

Various averaging time conversions have been used which account for different stability classes. Since AERMOD does not make use of Pasquill-Gifford stability class, this information will not be available. The Duffee, O'Brien and Ostojic (1991) stability dependent formula to convert modelled values to alternative averaging times is:

Equation 1

$C_l = C_0 \times (t_0/t_l)^n$

where:

t_1 = the longer averaging time

t_0 = the shorter averaging time

n = the stability dependant exponent (see below)

Stability Class	**n**
A&B	0.5
C	0.33
D	0.20
E&F	0.167

For example, a 1 hour concentration can be converted to a 24 hour average concentration as follows:

Equation 2

C 24 hour = C 1 hour x 60 min/[24 hr *(60 min/hr)])n

where: C 1 hour and C 24 hour are the maximum average concentrations respectively.

Equation 1 above would use the value of n for the stability that gave the highest modelled 1 hour concentration. To estimate a maximum 10 minute average for odour standards, equation 1 with 10 minutes as the shorter averaging time would be used. Again the value of n would be for the stability class that gave the highest modelled 1 hour concentration. A wide range in power law exponents is found in the literature, the corresponding 60-minute to 10-minute factors would vary from less than 1.4 to 2.5.. A summary of EMB conversion factors are provided in Table A.

- **Table B1: Averaging Time Conversion Factors**

Convert from \ Convert to	10 min	½ hour	1 hour	8 hour	24 hour	Annual
10 min	1	1/1.36*		-	-	-
½ hour	1.36*	1	1/1.2	0.5	1/3	1/15
1 hour	1.65	1.2	1	0.6	0.4	1/12.5
8 hour		1/0.5	1/0.6	1		
24 hour		3	2.5		1	0.2
Annual		15	12.5		5	1

Source: Ministry of the Environment, Air Dispersion Modelling Guidelines for Ontario, April 2004