Environmental Protection Agency

Office of Environmental Enforcement (OEE)

Air Dispersion Modelling from Industrial Installations Guidance Note (AG4)

Johnstown Castle Estate
Wexford, Ireland.

Acknowledgments

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PREFACE

Ireland is fortunate in having excellent ambient air quality with levels of pollutants well below the environmental quality standards specified under European legislation. One of the roles of the EPA is to contribute towards the maintenance of a high quality environment by ensuring that large scale industrial activities, which are licensed by the EPA, do not have an adverse impact on air quality.

Atmospheric dispersion modelling is an important tool in determining the impact on air quality of a proposed or existing activity. However, the reliability of results from dispersion modelling studies is dependent on many factors such as the robustness of the input data used in the model, the suitability of the model itself and the appropriate interpretation of the model results.

This guidance document sets out recommended approaches for the completion of modelling studies and should allow for improved consistency and reliability in modelling reports submitted to the EPA. Whilst this guidance should typically be regarded as best practice, the recommendations are not in any way binding, though justification should normally be provided where significant deviations from best practice are applied.

It is hoped that this guidance will be of use to both operators and consultants in preparing a good quality, reliable and accurate air quality impact assessment.

This guidance may be revised from time to time and the latest version will be available on the EPA website, www.epa.ie.

1.0 INTRODUCTION

This guidance note seeks to present general principles and suitable methods that may be used to assess and report on the impact of air emissions from EPA licensed industrial installations. The guidance note is aimed at practitioners and, as such, assumes a general understanding of the theory of air dispersion modelling and the tools available to undertake an assessment. Should the modeller be uncertain about the appropriateness of any aspect of the modelling assessment, particularly where the assessment is of a complex nature, it is advisable to discuss the model selection process and modelling approach with the EPA prior to carrying out a detailed assessment. In relation to completion of dispersion modelling studies as part of licence applications, it is always recommended that the applicant discuss relevant and significant aspects of the activity with the EPA prior to proceeding with the application process. The guidance, where necessary, has highlighted external references where more details on a particular topic can be sourced.

The guidance note has several main aims:

- To outline a set of minimum standards which an air modelling assessment should adhere to;
- To provide a best practice guide for modellers carrying out and reporting on dispersion modelling assessments;
- To ensure that air dispersion modelling studies are carried out with sufficient accuracy and reliability and that the report details the methodology and results in a clear and robust fashion;
- To ensure that assessments are conservative and thus prioritise the protection of human health and the environment.

From a technical viewpoint, the guidance note endeavours to:

- Ensure that there is a sound scientific basis to the modelling approach;
- Identify a consistent procedure for selecting screening versus advanced models;
- Identify a consistent methodology for the selection of the most appropriate advanced air dispersion model;
- Ensure that the complexity of the modelling assessment is consistent with the risk of adverse impacts from an installation;
- Ensure consistency of model application and scope such that professional differences are minimised and that assessments are of a uniform quality;
- Reduce errors in model set-up, application, interpretation and reporting.

In subsequent sections the guidance note will focus on the following topics:

- A short discussion on air dispersion modelling theory;
- Application and benefits of air dispersion modelling;
- A short discussion on the most commonly used screening and advanced models;
- A suitable approach to the model selection process;
- Technical topics in air dispersion models which warrant special attention including meteorology, land use, terrain, building downwash, deposition and cumulative assessments;

- Reporting requirements;
- Air dispersion modelling checklist.

2.0 AIR DISPERSION MODELLING THEORY

An air dispersion model is a tool that is used to assess the air quality impact of an emission source within a defined modelling domain. Rather than to replicate atmospheric processes in detail, the purpose of a dispersion model is to perform a mathematical approximation of dispersion and to provide a means for estimating ambient pollutant concentrations at a given location. An overview of the modelling process and the theory behind some of the topics covered in this guidance note is provided below. Further details on the theoretical aspects of air dispersion modelling are widely available[1-5].

2.1 Steps Required To Undertake An Air Dispersion Modelling Assessment

Before selecting an appropriate model, the question should be asked as to whether an air dispersion model is required at all. In some cases, it may be possible to scope out an emission point which is clearly insignificant and does not merit a screening modelling assessment (see Section 5.0).

Shown in **Figure 2.1** is a brief overview of the steps which are required in order to undertake an air dispersion modelling assessment. Task 2, model input, is generally the most critical aspect of the modelling process and requires the most time and resources to ensure that the modelling assessment is undertaken successfully.

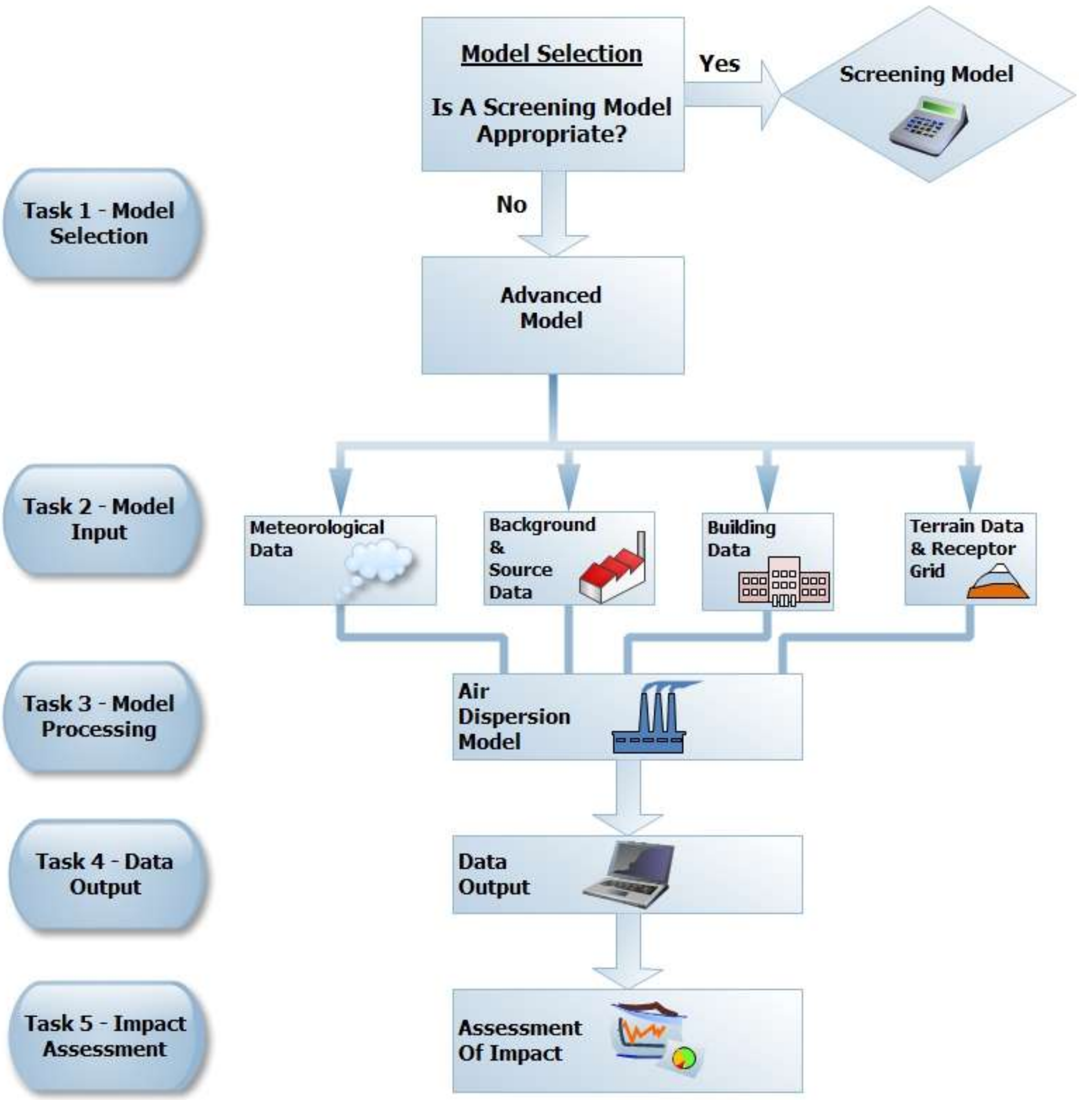


Figure 2.1 Flowchart of the tasks required when undertaking an air dispersion modelling assessment

2.2 Overview of Modelling Process

The process of dispersion modelling firstly involves gathering specific information in relation to the emission source(s) and site(s) to be assessed. This includes:

- *Source information:* Emission rate, exit temperature, volume flow, exit velocity, etc.;
- *Site information:* Site building layout, terrain information, land use data;
- *Meteorological data:* Wind speed, wind direction, temperature, cloud cover;
- *Receptor information:* Locations using discrete receptors and/or gridded receptors.

The model uses this specific input data to run various algorithms to estimate the dispersion of pollutants between the source and receptor. The model output is in the form of a predicted time-averaged concentration at the receptor. These predicted concentrations are added to suitable background concentrations and compared with the relevant ambient air quality standard or guideline. In some cases, post-processing can be carried out to produce percentile concentrations or contour plots can be prepared for reporting purposes.

2.3 Gaussian Plume and Lagrangian Puff Models

Both Gaussian plume and Lagrangian puff models are referred to in this document. Gaussian plume models predict pollutant concentrations based on the assumption that both the vertical and horizontal dispersion of the continuous plume is represented by a Gaussian or normal distribution around the plume centreline. Some models use skewed Gaussian profiles to allow for updrafts and downdrafts under convective conditions (see Section 4.0). The concentration within the plume is proportional to the emission rate and inversely proportional to the wind speed at the point of release. Therefore, at wind speeds close to zero, the predicted concentration approaches infinity and the Gaussian representation of the plume is no longer valid. A key supposition of Gaussian plume models is that the meteorological conditions between the source and the receptor are constant for each modelled hour (steady state assumption). The limitations of this assumption are discussed in Section 5.2.

The Lagrangian puff model's approach is to follow the trajectory of instantaneous releases from the emission source. The continuous plume is represented by a series of discrete packets of pollutant material. The total concentration at the receptor is then calculated based on the contribution of all nearby puffs. Puff models may also use the Gaussian distribution to describe the dispersion of pollutants within each puff.

2.4 Turbulence in the Boundary Layer

The atmospheric dispersion of pollutants is most important within the boundary layer, and characterisation of turbulence in this region is a key element of dispersion modelling. The boundary layer (also known as the atmospheric or planetary boundary layer) is the lowest layer of the atmosphere in contact with the earth's surface. At the top of the boundary layer is a temperature inversion, which represents the transition to the free troposphere. Typically during daytime a convective boundary layer of turbulent air grows and can be up to 2km in thickness(1). Near sunset, the turbulence weakens to form a neutral residual layer below the temperature inversion. At night the air generally cools over the surface to form a stable boundary layer below the residual layer(4). The night-time boundary layer can be as low as tens of metres(1). A stable boundary layer can also form during the day or night when air is carried across a relatively cooler land or water surface.

Many historical dispersion models described stability within the boundary layer using the Pasquill-Gifford (P-G) stability class scheme(6,7), which uses six separate categories to define stability based on the meteorological parameters: insolation (i.e. incoming solar radiation), wind speed and cloud cover. Turner(8) modified this scheme to produce a system that classified seven stability categories (ranging from extremely unstable to extremely stable) using an objective interpretation of hourly meteorological data (specifically the net radiation

index and cloud cover). This objective method was adapted for use in many dispersion models including ISCST3 and SCREEN3.

Several limitations to the P-G classification have been identified. One disadvantage of the scheme is that it is subjective in regards to defining insolation and cloud cover. A second disadvantage is the discrete nature of the stability categories which can mean a change from one stability classification to another can lead to a change of up to a factor of three in the estimated hourly concentration at a downwind receptor[(2)]. A third limitation is that the scheme does not allow for the observed variation in boundary layer parameters with height.

In response to these limitations, "new generation" air dispersion models have been developed based on what is known as planetary boundary layer (PBL) theory based on similarity (non-dimensional) relationships. Examples of these new generation models include AERMOD, ADMS 4 and CALPUFF. PBL theory recognises that, when combined, certain meteorological parameters used to describe boundary layer turbulence (such as friction velocity and Obukhov length) are independent of the spatial scale of that turbulence. Thus, appropriate similarity scaling factors can be used to model the boundary layer and to calculate a vertical profile of the boundary layer turbulence. Advantages of these models over the older-generation models are that the atmosphere is described as a continuum and the meteorological parameters and derived turbulence fluctuations are allowed to vary with height leading to a more physically realistic description of the atmosphere.

On a more local scale, an internal boundary layer can form within the boundary layer when air is modified by flow over a different surface[(4)]. A thermal internal boundary layer (TIBL) is formed when this transition is associated with a change in surface temperature. A TIBL is typically formed when stable marine air flows onshore at a coastline, and a gradually growing turbulent region within this stable marine air is formed. If a tall stack (there is no set definition of "tall stack" although Good Engineering Practice (GEP) only applies to stacks greater than 65m) is located near the coastline, then the plume may be emitted into stable air above the TIBL. As the plume is carried inland it eventually converges with the TIBL leading to turbulent mixing downward towards the surface. This situation is known as shoreline or coastal fumigation. Coastal fumigation can lead to elevated pollutant concentrations close to the coastline and although it may occur infrequently in Ireland, it should be considered when tall stacks (>65 m) are located near the coastline. Coastal fumigation represents a situation that has required specific algorithms to be developed for dispersion models.

3.0 APPLICATIONS, BENEFITS & LIMITATIONS OF DISPERSION MODELLING

Air dispersion modelling provides a cost-effective means for assessing the impact of air emission sources, the major focus of which is to determine compliance with the relevant ambient air quality standards. Models can also be used for planning, design and management of emissions from installations as discussed below. Note that some of the model applications detailed are limited to specific dispersion models. The requirements of the modelling study and the capability of the model should be considered in the model selection process (see Section 5.0).

Planning & Design of New Installations

At the planning and design stage of a new development, dispersion modelling can be used to determine the appropriate location, stack height and emission parameters for single or multiple sources. Various emission options can be modelled to determine the most appropriate strategy for emissions management at the installation (see below). Furthermore, the results of deposition modelling of hazardous pollutants (e.g. PCCDs/PCDFs, heavy metals) can be used as key inputs into risk assessment modelling. Model output options such as contour plotting provide a useful visual means of presenting the impact of a new installation to the public in a non-technical manner.

Reviewing Options for Air Emissions Management

Dispersion modelling provides a versatile means of assessing various emission options for the management of emissions from existing or proposed installations. Modelling can be used to review the following:

- *Individual source contributions:* For installations with multiple sources, the individual contribution of each source to the maximum ambient predicted concentration can be determined.
- *Variable emissions:* Modification in emission concentrations (e.g. as a result of process variations, start-up, shut-down or abnormal operations) can be modelled on an hourly, daily or monthly basis.
- *Air quality hotspots:* The peak and long-term maximum ambient pollutant concentrations in the region of a installation can be established. This information is useful for specification and planning of ambient air monitoring programmes.

The above options can be used to determine the most cost-effective strategy for compliance with ambient air quality limit values. Models are particularly useful under circumstances where the maximum ambient concentration approaches the ambient air quality limit value and provide a means for establishing the preferred combination of mitigation measures that may be required including:

- Stack height increases;
- Reduction in pollutant emissions through the use of air pollution control systems (APCS) or process variations;
- Switching from continuous to non-continuous process operations or from full to partial load.

Cumulative Assessments

A cumulative impact assessment is carried out if it is expected that the impact of two or more installations will overlap. Air dispersion modelling can be used to model numerous installations and to investigate the impact of individual installations and sources on the maximum ambient pollutant concentrations (as outlined in Section 6.6).

Model Limitations

Each dispersion model is designed to approximate pollutant dispersion within a defined set of meteorological and physical parameters. Specific models do however have certain limitations with regard to assessing specific model scenarios (e.g. multiple sources, complex terrain, coastal fumigation). The model selection process outlined in Section 5.0 provides a means for determining the appropriate dispersion model to use for each application.

Dispersion models are also subject to both reducible and inherent (non-reducible) uncertainties. The reducible uncertainties lie within the set of model input data and also result from the limitations in the model formulation. Further details of model accuracy and assessment of model sensitivity to certain input parameters are provided in Section 6.11.

4.0 SUMMARY OF COMMONLY USED MODELS

4.1 Screening Models

A screening air dispersion model is a simple tool for the conservative assessment of single sources. Screening dispersion models provide a more simplified representation of atmospheric dispersion than the more advanced models but are more straightforward to use as the input requirements are less complicated. Because of their conservative nature they represent a first-step in the assessment of point sources, although they can have many limitations (e.g. with regard to receptor locations, pollutant averaging times, and output options). Should the results of a screening model predict an exceedance of the air quality standards, then a more advanced model should be used. A brief description of the commonly used screening models in Ireland is provided below. The key features of each model are provided in **Appendix A**.

4.1.1 SCREEN3

SCREEN3 is a steady-state Gaussian plume model which uses worst-case meteorological data to predict ambient pollutant concentrations resulting from single continuous emission sources(9). The dispersion calculations used by the model are those of the ISC3 dispersion model(10) and are based on the assumptions detailed in the USEPA Screening Procedures document(11).

SCREEN3 is currently the regulatory screening air dispersion model in the USA, but it will be replaced by AERSCREEN(12) as the preferred screening model upon approval by the USEPA(13). When AERSCREEN becomes available it should be used in preference to SCREEN3.

The input requirements and model outputs are summarised in **Table 4.1**. The model can be downloaded free from the USEPA website (http://www.epa.gov/scram001/dispersion_screening.htm). A graphical user interface is available as freeware from Lakes Environmental Software (http://www.weblakes.com).

4.1.2 ADMS-SCREEN

ADMS-Screen is a Gaussian type steady-state plume model which uses worst-case and internal meteorological data to predict the ambient pollutant concentrations resulting from single continuous point sources(14). The plume rise, dispersion and building downwash calculations performed by the model use the algorithms of the advanced air dispersion model ADMS 4(15). The model is designed to predict ambient concentrations that are equal to or greater than those predicted by ADMS 4.

The input requirements and model outputs are summarised in **Table 4.1**. ADMS-Screen is available to purchase from Cambridge Environmental Research Consultants (CERC). Further details are provided on the CERC website (http://www.cerc.co.uk/).

4.1.3 AERSCREEN

AERSCREEN is a steady-state Gaussian plume model which uses worst-case meteorological data to predict the ambient pollutant concentrations resulting from single continuous emission sources(12). The plume rise, dispersion and building downwash calculations performed by the model use the algorithms of the advanced air dispersion model AERMOD(16). The model is designed to predict ambient concentrations that are equal to or greater than those predicted by AERMOD. AERSCREEN is currently being developed and tested by the USEPA and is expected to be released in the near future(12).

The input requirements and model outputs are summarised in **Table 4.1**. A beta version of the model is expected to be available to download free from the USEPA website (http://www.epa.gov/scram001/dispersion_screening.htm) in the near future. It is advisable to use a graphical user interface (GUI) software package in order to prepare an accurate input file for the model.

Model Inputs & Outputs	SCREEN3	ADMS-Screen	AERSCREEN
Stack Details	Emission rate (g/s), stack height (m), stack diameter (m), gas exit velocity (m/s), or volume flow (m^3/s), temperature (K)	Emission rate (g/s), stack height (m), stack diameter (m), gas exit velocity (m/s) or volume flow (m^3/s), temperature (°C)	Emission rate (g/s), stack height (m), stack diameter (m), gas exit velocity (m/s) or volume flow (m^3/s), temperature (K)
Meteorology Inputs	Ambient temperature (K)	None for short-term calculations. Specify site location (UK only) for long-term calculations[Note 1]	Min / max ambient temperature, min wind speed, anemometer height, surface characteristics
Land Use Inputs	Urban / Rural Option	None	Urban / Rural Option. Surface characteristics
Terrain Inputs	Options for simple, simple elevated or complex	None - simple terrain only	Digital elevation model (DEM) file to run AERMAP
Building Downwash Inputs	Building dimensions and stack location relative to building	Building dimensions and stack location relative to building	Building dimensions and stack location relative to building
Output concentrations	Max 1-hour or max 24-hour. Conversion to other averaging times using adjustment factors	1-Hour, 24-hour, annual average concentrations and percentiles	1-Hour. Conversion to other averaging times using adjustment factors
Output files	Text file	Range of file types for subsequent analysis and contour plotting	Range of file types for subsequent analysis and contour plotting

[Note 1] Internal meteorological dataset used with data from UK Met Office. Northern Ireland data may be used if data for the Republic of Ireland is not available.

Table 4.1 Overview of SCREEN3, ADMS-Screen and AERSCREEN Screening Models

4.2 Advanced Models

Advanced air dispersion models are usually based on more modern scientific theories and more complex mathematical formulations than screening dispersion models. Advanced models can assess the impact of large installations with multiple sources and numerous buildings. Detailed input data regarding meteorology, land use and terrain are required by these models in order to allow them to represent the atmospheric processes contributing to pollutant dispersion. Significant data pre-processing is often required to prepare the input files used by these models.

Advanced models may have limitations in their ability to assess certain scenarios (such as calm hours, terrain downwash and coastal fumigation). In circumstances where these scenarios may have the potential to lead to high ambient concentrations, it is important to determine the suitability of the particular advanced model in assessing the maximum impact from an installation. An outline of the advanced dispersion models in general use in Ireland is provided below, including a discussion on the input requirements. The key features of each model are provided in **Appendix A**.

4.2.1 AERMOD

AERMOD is a steady-state Gaussian plume model which can simulate dispersion from multiple sources using up-to-date concepts regarding boundary layer characterisation and dispersion(13,16). The meteorological data used by the model is prepared by the AERMET meteorological pre-processor(17). When the effects of complex terrain are required, the AERMAP terrain pre-processor(18) is used.

The model has USEPA regulatory status(13) and is available to download free from the USEPA website (http://www.epa.gov/scram001/dispersion_prefrec.htm). It is advisable to use a graphical user interface software package in order to prepare an accurate input file for the

model. These are available to purchase from companies such as Lakes Environmental Software (http://www.weblakes.com) or Trinity Consultants (http://www.breeze-software.com).

AERMET Meteorological Pre-processor

The AERMET meteorological pre-processor[17] produces two types of meteorological input files required by AERMOD, a surface file which contains various meteorological and surface scalar parameters, and a profile file which consists of meteorological data at more than one height for use when undertaking an on-site monitoring programme. AERMET is available from USEPA website (http://www.epa.gov/scram001/metobsdata_procaccprogs.htm). As with AERMOD, it is advisable to use a graphical user interface software package in order to prepare an accurate input file for the model. These packages are commercially available.

The input requirements for AERMET include surface characteristics (such as surface roughness, Bowen ratio, and albedo) and hourly meteorological data (wind speed, wind direction, cloud cover, and temperature). Morning sounding data is not incorporated into surface meteorological (.sfc) files in Ireland due to incompatibility between the time of the Irish soundings and the day/night transition. The profile meteorological (.pfl) file is used solely for processing on-site weather data, collected at multiple levels. For the majority of modelling assessments in Ireland, no on-site meteorological data is available, and thus the profile file defaults to the data contained in the surface meteorological file (wind speed, wind direction and temperature).

AERMET requires user input data on site-specific surface characteristics. Recent guidance by the USEPA regarding the implementation of AERMOD provides the methods for determining the correct surface characteristics required by AERMET[19]. The AERSURFACE tool has been developed to estimate the surface characteristics for input to AERMET, but the data input requirements for AERSURFACE are not currently available in Ireland. More detail on meteorological pre-processing is given in Section 6.2.

AERMAP Terrain Pre-processor

The AERMAP terrain pre-processor[18,20] is used to prepare the terrain information required by AERMOD for complex terrain scenarios. AERMAP sets a hill height scale, which is the height that has the greatest influence on dispersion, for each individual receptor modelled by AERMOD. AERMAP requires terrain information for the modelling domain in the form of a Digital Elevation Model (DEM) file. More detail on terrain pre-processing is given in Section 6.2.

4.2.2 ADMS 4

ADMS 4 is an advanced steady-state Gaussian type plume model which can simulate dispersion from multiple sources[21]. A puff model for the assessment of instantaneous releases of pollutants is also included. ADMS 4 uses an in-built meteorological pre-processor developed by the UK Met Office and also includes a terrain convertor utility for preparation of terrain data in ADMS 4 format.

ADMS 4 is available to purchase from Cambridge Environmental Research Consultants (http://www.cerc.co.uk/). The package includes a graphical user interface.

Meteorological Pre-processor

Meteorological pre-processing is generally less involved in ADMS than AERMOD. Included with ADMS 4 is a pre-processor that processes raw meteorological data and determines the boundary layer parameters required by the model. Almost 30 individual parameters can be included in the meteorological data input for processing. The minimum data requirements for ADMS 4 are wind speed, wind direction and one of the following (a) reciprocal of Obukhov Length, (b) surface sensible heat flux and (c) cloud cover, time of day and time of year. Specific localised data is also required when modelling coastal fumigation and plume visibility. Further details of input requirements are detailed in the ADMS 4 User Guide[21].

ADMS Terrain Convertor

Modelling of terrain requires the preparation of an input file with x- and y-coordinates and terrain heights for the modelling domain. The ADMS Terrain Convertor utility can be used to convert Irish National Grid Digital Terrain Model (DTM) files into the required format for the model.

4.2.3 CALPUFF

CALPUFF is a multi-layer, multi-species non-steady-state Gaussian puff dispersion model that simulates the effects of time- and space-varying meteorological conditions on pollutant transport, transformation, and removal(13,22). The CALPUFF system requires significant resources with regards to meteorological data, terrain data and land-use inputs but its value lies in its ability to model non-steady state scenarios that are outside the capabilities of both AERMOD and ADMS 4 (see **Appendix B**).

5.0 MODEL SELECTION PROCESS

The EPA does not recommend any individual models and a policy on selection of dispersion models has been developed by the Agency and is included in **Appendix C**. In essence the modeller should be able to demonstrate that the model chosen is suitable for the situation being modelled.

Prior to selecting an appropriate model, the question should be asked as to whether an air dispersion model is required at all. In some cases it may be possible to screen out an emission point which is clearly insignificant and does not merit a screening modelling assessment. The UK Environment Agency H1 methodology[(23)] and associated software (available from http://www.environment-agency.gov.uk/business/topics/pollution/37231.aspx) provides a means to screen out insignificant releases to air and to identify those emission points which are significant through the use of simple algorithms. The dispersion factors used in the methodology assume worst case dispersion conditions, with no allowance made for buoyancy or momentum plume rise, and thus the process contributions calculated are likely to significantly over-estimate the actual impact.

5.1 Screening vs. Advanced Models

Once an air emission point has been identified as significant, the first stage in the model selection process is to decide whether to use a screening or advanced model. As discussed in Section 4.1, screening models are designed to be conservative in their prediction of ambient pollutant concentrations. Thus, if the ambient pollutant levels predicted by a screening model, including background concentrations, are below the relevant ambient air quality standard for the pollutant assessed, then further assessment with a more advanced model may not be required. The assessment using a screening model should always be conservative (e.g. using maximum emission rates only). Although some screening models can account for building downwash (e.g. ADMS-Screen, AERSCREEN), they are generally not suitable for many complex modelling scenarios and should not be used to assess major industrial installations such as power stations, cement manufacturing installations or incinerators. Some screening models are also limited in terms of their presentation of modelling results.

Some important questions to consider before deciding on the use of a screening model are provided below and shown graphically in **Figure 5.1**:

How many stacks will be assessed?

The screening models discussed in this document will only model a single emission source. Where more than one emission point is to be assessed, the maximum predicted concentration for each individual point source can be combined to obtain a worst-case impact of all sources. Alternatively, the USEPA Screening Procedures document[(11)] provides a method for merging similar stacks in close proximity into a single representative emission point. These options may lead to predicted pollutant levels above the ambient air quality standards and in such circumstances an advanced model will be required.

Is there complex terrain in the region of the site?

Complex terrain should be considered if the modelling domain contains regions of irregular variations in topography, in particular features that will affect the dominant wind flow. Both AERSCREEN and SCREEN3 are capable of modelling complex terrain, while ADMS-Screen is limited to simple terrain. The model formulation of AERSCREEN is equivalent to that of AERMOD[(16)] and the limitations of the AERMOD formulation should be known (see Section 6.2). The formulation for SCREEN3 is taken from the VALLEY screening model[(9)] and is now outdated. When the development and validation of AERSCREEN is complete, it will replace SCREEN3 as the regulatory screening model[(12)]. SCREEN3 can currently be used to model complex terrain scenarios but the greater uncertainty in the predictions should be borne in mind. Section 6.2 should be consulted to determine whether the installation is located in an area of complex terrain.

Will a cumulative assessment be required?

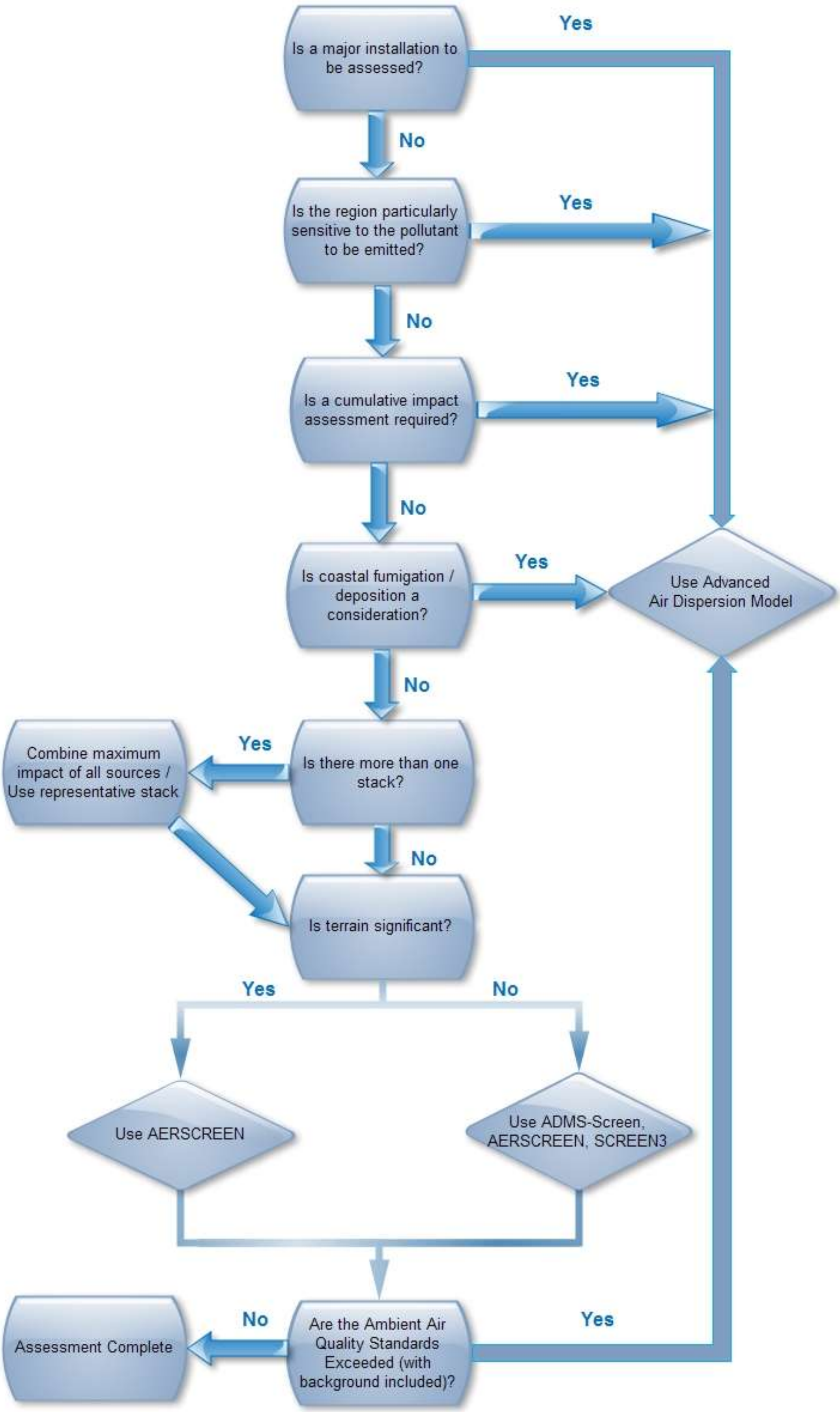
Should there be a requirement for a cumulative assessment of the impact of other emission sources in the region then an advanced dispersion model is required.

Is pollutant deposition expected to be significant?

Screening models cannot model the effects of pollutant deposition and thus an advanced dispersion model is required (e.g. PCDDs/PCDFs, heavy metals, dust). PCDD/PCDFs and heavy metals are present in both vapour and particulate phases and the relevant guidance should be used to assess the gaseous and particulate deposition (see Appendix G and the references therein).

Is coastal fumigation a consideration?

If a source with a tall stack (greater than 65m) is located in a coastal region, then the effects of coastal (or shoreline) fumigation may be significant (see Section 2.0). The US EPA[13] has recommended the use of the Shoreline Dispersion Model (SDM) on a case-by-case basis to treat shoreline fumigation. AERSCREEN and ADMS-Screen cannot treat coastal fumigation although SCREEN3 does have an algorithm dealing with this scenario.



Note: When AERSCREEN is approved by the USEPA, SCREEN3 is likely to be obsolete

Figure 5.1 Flowchart for selecting a Screening versus an Advanced Air Dispersion Model

5.2 Selection of Advanced Model

While the advanced models are superior to the screening models in terms of model formulation, accuracy and output options (e.g. calculation of percentiles, contour plots), they still have certain limitations that should be considered when selecting the appropriate advanced model to use. Moreover, although the results from advanced models are more reliable than screening models, a conservative approach is always recommended (e.g. by using maximum emission concentrations) to ensure that the assessment is sufficiently robust. Some questions that should be considered when selecting the appropriate advanced model are outlined below and shown graphically in **Figure 5.2**.

Information regarding the input, output and some theoretical aspects of AERMOD, ADMS 4 and CALPUFF is provided in Section 4.2. The benefit of producing more reliable results should be weighed against the cost implications of developing new input data (and possibly purchasing an alternative model) when some of the below questions are relevant. In some instances an awareness of an individual model's limitations during the assessment and review of modelling results may be sufficient, rather than resorting to an alternative model. Should the modeller be uncertain about the appropriateness of the model used, it is advisable to discuss the model selection process with the EPA prior to carrying out any detailed assessments.

Is the steady-state assumption appropriate?

As described in Section 2.0, the steady-state assumption is fundamental to Gaussian plume models such as AERMOD(16) and ADMS 4(21). Two conditions that can arise where the steady-state assumption may be no longer valid are as follows:

- ***Non-uniform meteorological conditions:*** If there are regions within the modelling domain that are complex due to significant terrain features or changes in land use (e.g. urban / rural interface or a valley or coastal region), then the assumption that the wind field within the entire modelling domain is constant breaks down;

- ***Dispersion over large distances:*** Gaussian plume models calculate concentrations in a straight line from source to receptor within the modelling domain for each hour. However they do not take into account the time taken for the plume to travel from source to receptor. Concentration calculations under low wind speeds may be made at receptors tens of kilometres from the source when it would be physically impossible for the plume to travel this distance. Furthermore, at large distances the steady-state assumption is unlikely to be consistent with reality. For this reason Gaussian plume models should only be used for predicting maximum concentrations within about 10km from the source.

Are there a significant number of calm hours?

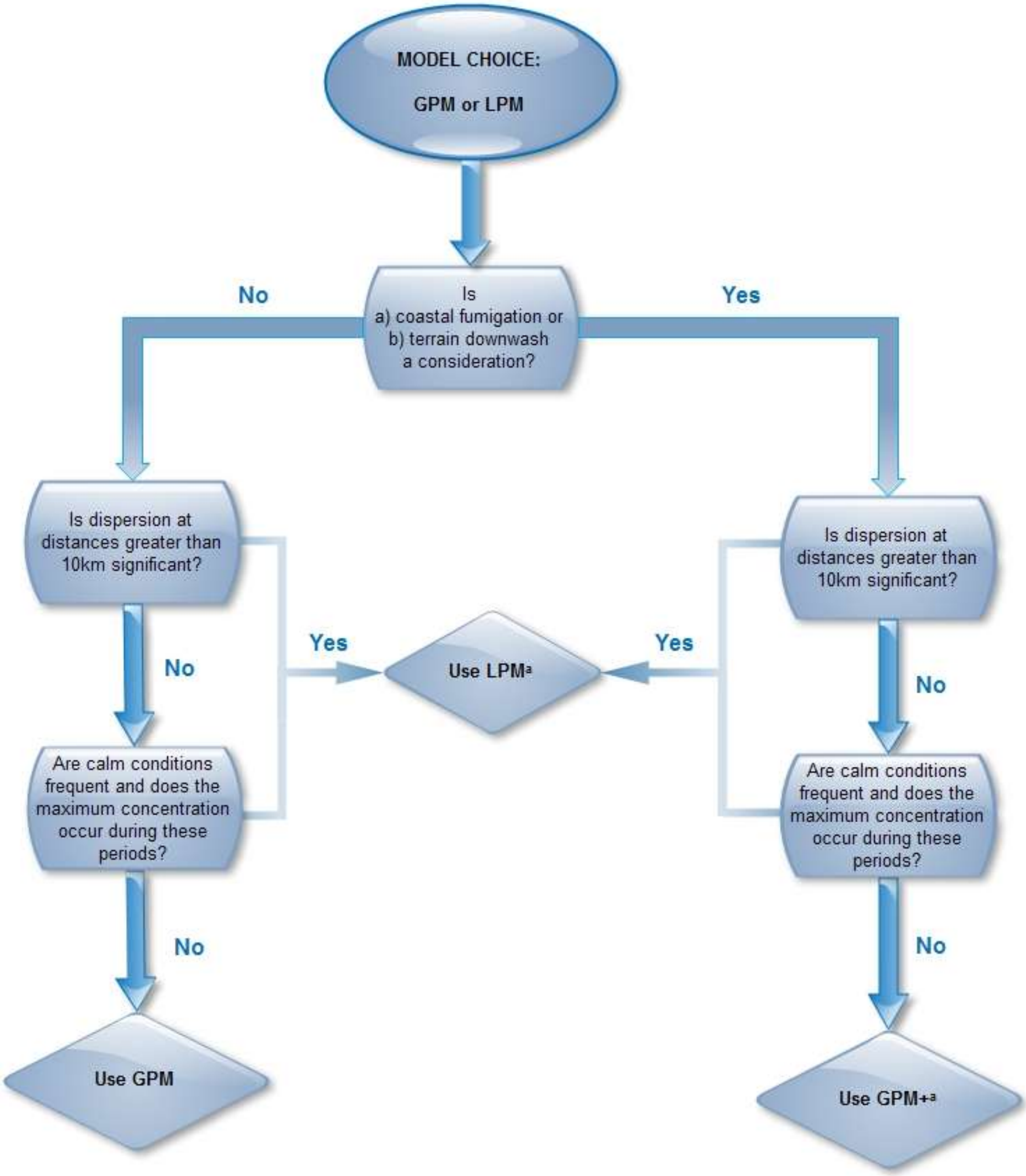
As discussed in Section 2.0, the Gaussian equation is not suitable for calculating concentrations at wind speeds approach zero. While techniques are used to process calm hours by AERMOD(16) and ADMS 4(21), these may not be sufficient if the percentage of calm hours is high or if such conditions are likely to lead to the highest pollutant concentrations.

Are terrain downwash effects significant?

Although AERMOD is capable of modelling in complex terrain, the model formulation is not as advanced as that used by ADMS 4 and CALPUFF, both of which can model the effects of terrain downwash and plume channelling (see Section 6.2).

Is coastal fumigation a consideration?

Both ADMS 4 and CALPUFF contain algorithms for calculating concentrations under fumigation conditions in the region of a coastline. The AERMOD dispersion model cannot model the effects of coastal fumigation.



GPM – Gaussian Plume Model (such as AERMOD or ADMS) which may or may not have terrain downwash and coastal fumigation options.

GPM+ - Gaussian Plume Model with terrain downwash & shoreline fumigation options (such as ADMS)

LPM – Lagrangian Puff Model (such as CALPUFF)

[a]: Alternatively, a Gaussian Plume Model (GPM) may be used whilst acknowledging a greater associated uncertainty (process contribution (PC) error is assumed to be ±100% rather than ±50%). When a GPM is applied under these circumstances, the PC under maximum operations should be no more than 50% of the ambient air quality standard (AQS) and less than this where the background concentration (BC) accounts for a significant fraction of the ambient air quality standard based on the formula below:

Maximum Allowable PC Using GPM = (AQS – BC) / 2.0

Figure 5.2 Indicative flowchart for selecting an Advanced Air Dispersion Model

6.0 IMPORTANT TOPICS IN AIR DISPERSION MODELLING

The modelled ground level concentrations produced by an air dispersion model are vitally dependent on the model inputs. Depending on the complexity of the model the inputs can range from a few basic parameters for screening models to a large number of input parameters for complex models.

What all models share is the need for accurate inputs to ensure that reducible errors are minimised. The accuracy of some inputs is particularly important; this is highlighted in detail below.

6.1 Meteorological Data

Selection Of Meteorological Station

Air dispersion models seek to simulate the dispersion of pollutants from the point of release to the point of impaction, which is generally the ground level concentration (GLC). The dispersion process is dependent on the underlying meteorological conditions and ensuring that the air dispersion model includes representative meteorological data is critical.

The USEPA(24) has defined meteorological representativeness as:

> "*the extent to which a set of* {meteorological} *measurements taken in a space-time domain reflects the actual conditions in the same or different space-time domain taken on a scale appropriate for a specific application*"

and has expanded on this definition(13) by outlining the factors to consider in the selection of appropriate meteorological data:

- Proximity of the meteorological station to the modelling domain;
- The complexity of the terrain;
- The exposure of the meteorological monitoring site;
- The period of time during which data is collected.

In this regard, the meteorological conditions of concern are those conditions which apply at the release height of the plume or the plume height (effective stack height) for buoyant plumes:

Met Eireann currently collects meteorological data at a range of locations as outlined in **Table 6.1** and **Appendix D**. The stations are located in an array of settings including coastal sites (such as Valentia, Belmullet, Malin Head and to a lesser extent Dublin Airport and Shannon Airport), in the proximity of complex terrain (such as Casement Aerodrome), in areas of relatively high elevation (such as Cork Airport and Knock Airport) and in areas of relatively simple terrain in rural locations (such as Mullingar or Johnstown Castle).

Station	Annual Mean Wind Speed (m/s)	Station	Annual Mean Wind Speed (m/s)
Belmullet	6.7	Malin Head	8.4
Birr	3.6	Mullingar	4.3
Casement	5.7	Roches Point	6.3
Claremorris	4.5	*Rosslare*	5.9
Clones	4.3	Shannon Airport	5.0
Cork Airport	5.7	Valentia	5.6
Dublin Airport	5.1	Johnstown Castle	Opened 2008
Kilkenny	3.3	Tucson-Ballyhaise	Opened 2008
Knock Airport	Opened 1986	Oak Park, Carlow	Opened 2008

Stations in italics are now closed but historical data is available.

Table 6.1 Annual mean wind speeds (averaged over the period 1961 – 1990) at stations operated by Met Eireann

Due to the low resolution of meteorological stations throughout Ireland, it is unlikely that meteorological stations will be located routinely within the modelling domain. Under these circumstances careful selection of the appropriate station will be necessary based on the above criteria. Due to the proximity of many meteorological stations to the coast, the land/sea interface will be an important consideration. Installations located more than 10 kilometres from the coast may be more appropriately assessed with an inland station which may be further from the modelling domain than a nearby coastal station.

A study by the UK Atmospheric Dispersion Modelling Liaison Committee (ADMLC)[25] into the portability of weather data for dispersion calculations found that the most important factor in the selection of a meteorological station was the annual mean wind speed. The study outlined a procedure to select the most appropriate site as follows:

- Estimate the mean annual wind speed in the region of the installation using a wind map (available from the Met Eireann website http://www.met.ie/climate/wind.asp);
- Calculate the ratio of the mean annual wind speed for the source and the mean annual wind speed for the nearby meteorological sites (as shown in **Table 6.1**);
- Choose a meteorological station with a mean annual wind speed ratio between 0.9 – 1.1 to estimate the dispersion from the site.

In relation to distance, the study found no systematic change of concentration estimate with distance and that mean wind speed rather than proximity was of most relevance. The study also investigated the correlation between wind direction, mean cloud cover and sunshine hours although none of these parameters showed correlations as high as that for wind speed. Although no strong correlation with wind direction was found in the study, it would be prudent to select a station which would be expected to have a similar wind direction profile to the region of interest. The report did however caution that in complex terrain or urban areas this correlation would probably not be reliable.

The individual wind roses for the selected meteorological station for each of the modelled years should be included in the modelling report with some comment on the prevailing wind directions, seasonal variations, average wind speeds, comparison to 30-year averages etc. An example wind rose is shown below in **Figure 6.1**.

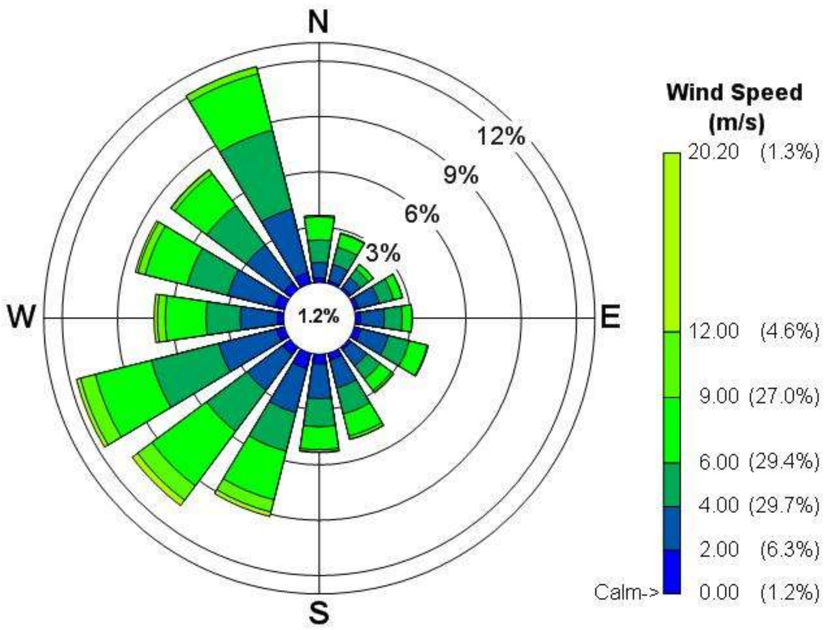


Figure 6.1 Example of a wind rose showing wind direction and wind speed frequency over a calendar year (Cork Airport 2007)

Length Of Meteorological Dataset

The USEPA has reviewed the length of the meteorological dataset necessary to ensure that worst-case meteorological conditions are captured. The recommendation by the USEPA(13) is that five years of data is appropriate. A review by the ADMLC(26) reporting on the work of a UK Met Office research group found that five and three year analyses gave good results for long-term mean and high percentile concentrations when compared to a ten-year mean although one year was considered insufficient.

It is recommended that a minimum of three years of meteorological data from an appropriate meteorological station should be used in the assessment. Furthermore, the most recent year of the data set used should have been compiled within the last ten years. Long-term averages or calculations of percentile concentrations should not extend for more than one year. Each individual year in the multiple year set should be modelled, with the highest predicted process contribution (PC) used as the basis for the assessment. Further guidance with regard to meteorological data selection and dataset length is provided in **Box 1**.

Data Capture

Meteorological data from fully manned Met Eireann stations (either sourced directly or obtained from software providers such as Trinity Consultants or Lakes Environmental) typically contains between 0.1% – 5% of missing data depending on the specific parameter. Semi-automatic stations however will typically have much greater data gaps particularly for cloud cover. Cloud cover, which is required in new generation models to calculate important surface parameters such as surface heat flux and friction velocity, is frequently the parameter with the lowest data capture due to the manual nature of data collection. The USEPA(24) has outlined procedures to fill the missing data gaps as outlined below, the goal of which is to provide a "best estimate" for the missing data:

- If a meteorological station has more than 10% missing data for each parameter/year then this parameter/year should not be used for modelling. The data should also have 90% data coverage on a seasonal basis.

- Where there are missing periods of a few hours, linear interpolation or persistence can be used. The guidance however does caution against this approach during the day/night transition periods.

- For longer time periods, data from a nearby representative station can be used. If no nearby representative station is available, linear interpolation over longer periods or the use of a seasonal average value is acceptable.

- Data from a dissimilar meteorological station may also be used to fill data but with a greater associated uncertainty in the data.

- Gaussian plume models are inversely proportional to wind speed and thus fail as the wind speed approaches zero. AERMOD ignores these hours in line with USEPA regulatory options. ADMS 4, in default option, does not model when winds at 10m are less than 0.75 m/s. However, ADMS 4 has an option to model under calm conditions using a weighted average of a normal "Gaussian" type plume and a radially symmetric plume where the weighting depends on the wind speed at 10m[(27)].

Guidance from New Zealand[(28)] has suggested that periods of up to seven days can be substituted using synthesized averages from a longer-term record of the station. The guidance further suggests that all calm periods should be reset to the threshold value which is 0.75 m/s in ADMS and 0.3 m/s in AERMOD.

When missing and calm data combined is greater than 2%, care should be taken when comparing modelled results to the one-hour limit values for NO_2 (18 exceedances allowed based on 8760 modelled hours) and SO_2 (24 exceedances allowed based on 8760 modelled hours). In this instance the data should be corrected to allow for the data gaps (i.e. at a data capture rate of 95%, the number of allowable exceedances will be 17 hours for NO_2 and 23 hours for SO_2).

Site-Specific Meteorological Monitoring

Site-specific meteorological monitoring may be required in particularly complex locations where there is no comparable representative Met Eireann station. However, the need for such site-specific meteorological monitoring in Ireland will be rare and is likely to be limited to larger installations that may be viewed as high-risk and are of a scale and magnitude that impacts may occur over tens of kilometres.

When site-specific meteorological monitoring is required, relevant technical documents[(24,29)] should be consulted to ensure that the siting of the station is appropriate and data collection techniques are sufficient to meet the data quality objectives (accuracy and precision) stated. The USEPA[(13)] has stated that one year of site-specific meteorological data is sufficient for modelling purposes, however, modelling with three to five years of off-site meteorological data should also be carried out for comparative purposes.

Site-specific stations typically collect wind speed, wind direction, temperature and humidity. It is unlikely that cloud cover will be collected at a site-specific station. However, cloud cover (along with temperature) is typically representative of a larger domain than wind speed or wind direction and thus this parameter can usually be sourced from the nearest Met Eireann station.

BOX 1: Guidance In Relation To Meteorological Data

The guidance in relation to meteorological data is as follows:

- A minimum of three years of meteorological data from an appropriate station should be used in the assessment. The station should be the nearest one that has a similar annual mean wind speed (preferably between 0.9 – 1.1 of the site annual mean wind speed).

- The most recent year of the three year dataset should be within the last ten years (i.e. for an assessment undertaken in 2010, the oldest 3-year dataset should be 1998 – 2000).

- When modelling using multiple years of data, each year should be individually reported rather than reporting the overall averages.

- For each relevant averaging period (99.8^{th} %ile of 1-hour values, annual mean etc.) the highest result of any of the three years should be reported. It is likely that different averaging periods will have maxima in different years.

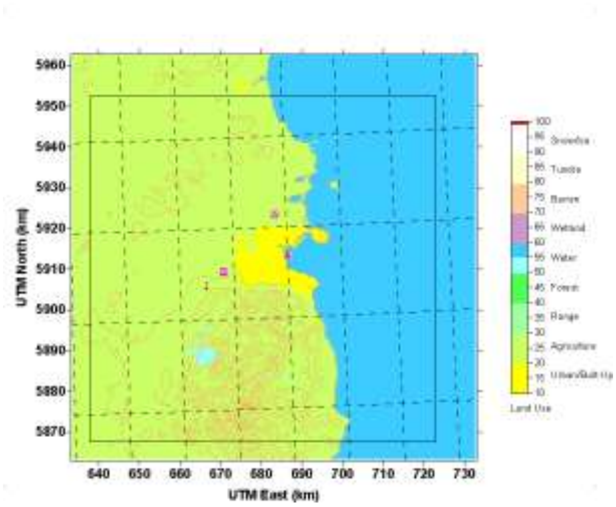
- Missing data should be replaced where feasible and the methodology employed detailed in the report alongside the frequency of calms, the conditions which lead to the highest ground level concentrations and any implications due to the level of missing or calm data (including corrections to the percentiles for short-term limit values).

- Site-specific monitoring or numerical weather modelling will not be routinely needed for air dispersion modelling.

6.2 Geophysical Data

Land Use

New generation models such as ADMS 4[21] and AERMOD[16] simulate the dispersion process using planetary boundary layer (PBL) scaling theory. PBL depth and the dispersion of pollutants within this layer are influenced by specific surface characteristics such as surface roughness, albedo and the availability of surface moisture.



Surface roughness is a measure of the aerodynamic roughness of the surface and is related to the height of the roughness element[30]. Albedo is a measure of the reflectivity of the surface whilst the Bowen ratio (in AERMOD) and the modified Priestley-Taylor parameter (in ADMS 4) are measures of the availability of surface moisture.

Both the ADMS 4 user manual[21] and AERSURFACE[31] have representative values for these parameters depending on land use type. In ADMS 4, options can be used to enter either a constant or hourly varying values of the surface rougness, albedo and Priestly-Taylor

parameters. Furthermore, ADMS 4 allows surface roughness to vary at each terrain grid point. AERMET allows surface parameters to vary on a monthly or seasonal basis (winter is defined as continuous snow coverage and thus will not be applicable to Ireland).

In relation to AERMOD, detailed guidance for calculating the relevant surface parameters has been published(19). The most pertinent features are:

- The surface characteristics should be those of the meteorological site rather than the installation;
- Surface roughness should use a default 1km radius upwind of the meteorological tower and should be based on an inverse-distance weighted geometric mean. If land use varies around the site, the land use should be sub-divided by sectors with a minimum sector size of 30º;
- Bowen ratio and albedo should be based on a 10km grid. The Bowen ratio should be based on an un-weighted geometric mean. The albedo should be based on a simple un-weighted arithmetic mean;
- The AERSURFACE pre-processor currently only accepts NLCD92 land use data which covers the USA. Thus, manual input of surface parameters will be necessary when modelling in Ireland. Ordnance survey discovery maps (1:50,000) and digital maps such as those provided by the EPA, National Parks and Wildlife Service (NPWS) and Google Earth® will be useful in determining the relevant land use in the region of the meteorological station. The Alaska Department of Environmental Conservation has issued a guidance note for the manual calculation of geometric mean for surface roughness and Bowen ratio for use in AERMET(32).
- Sensitivity studies(33-35) have found that AERMOD is very sensitive to the surface roughness parameter particularly for installations with low stack heights (5-10m) and with little associated buoyancy. Variations of up to a factor of two have been observed for the annual mean ground level concentration based on variations to the surface roughness parameter. Similar analysis of the impact of varying the bowen ratio and albedo have found these parameters to be much less sensitive.

Urban Versus Rural

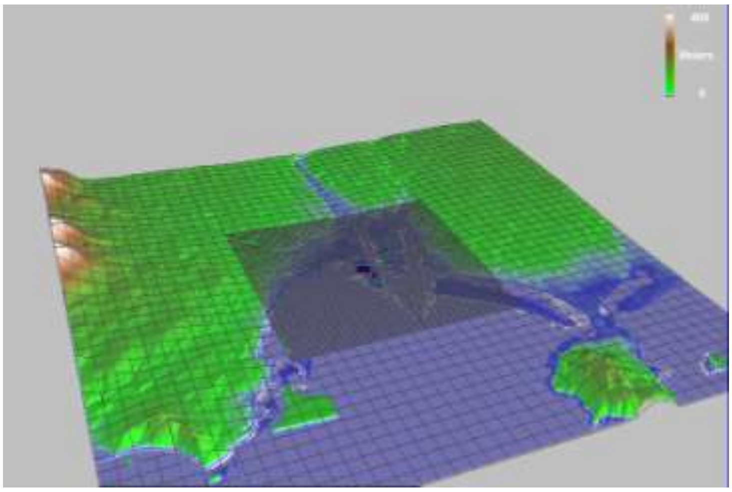
ADMS 4 uses the minimum Monin-Obukhov (or Obukhov) length to allow for the heat island effect in cities. A default of 1m is used for rural areas with an option to increase this value in urban areas ranging from 10m in small towns to 100m in large conurbations.

AERMOD requires the user to determine which sources are located in an urban area. Sources located in an urban area are subjected to increased surface heating under stable conditions (night-time heat island effect). The procedure for determining which sources are located in an urban area is as follows(19):

- The urban option should be selected for sources located in urban areas regardless of where the meteorological station is located;
- The land use within a 3km radius of the source should be determined;
- If greater than 50% of the area is either industrial, commercial or compact residential(13,36) the source should be classified as urban, otherwise the site should be classified as rural;
- If modelling is being conducted over a whole urban area all sources should be classified as urban even if some sources would be defined as rural using the above definition;
- If the source is defined as urban, the model requires the population (and name) of the urban area and the surface roughness (default of 1m). The population size has been found to correlate well with urban-rural temperature differences.

A second option using population density is considered by the USEPA to be less reliable and is not encouraged in this guidance note.

Terrain



The presence of terrain can lead to significantly higher ambient concentrations than would occur in the absence of the terrain feature. In particular, where there is a significant relative difference in elevation between the source and off-site receptors large ground level concentrations can result. Thus the accurate determination of terrain elevations in air dispersion models is vital.

Terrain data in Ireland can be obtained from Ordnance Survey Ireland (OSi) in Digital Terrain Model (DTM) format. The terrain data is available in tiles of 20km x 20km with 10m grid postings. The data is available in either Irish Grid or Irish Transverse Mercator (ITM) format with a vertical accuracy of 2.5m. It is recommended that the 20km x 20km tile is centred at the source when the data is requested.

In order to use the digital terrain data in either AERMOD or ADMS 4, conversion of the data will be necessary. The AERMOD terrain pre-processor (AERMAP) requires terrain data in USGS Digital Elevation Model (DEM) format. A convertor is available from software companies (Lakes Environmental and Trinity Consultants) to enable the conversion from DTM to DEM. ADMS 4 includes a terrain utility which is specifically designed to convert Irish Grid DTM files supplied by OSi into the correct format required by the model.

Simple Versus Complex Terrain

Many dispersion models have historically differentiated between simple terrain and complex terrain (including ISCST3 and SCREEN3). Complex terrain is defined as terrain above the effective stack height (which is the stack height plus an additional height due to the buoyancy of a hotter than ambient air plume).

Intermediate terrain is defined as terrain above stack height but below the effective stack height. Simple terrain is terrain below the top of the stack. However, simple terrain can be further divided into simple elevated terrain, which is terrain which exceeds the stack base but is below the stack height, and flat terrain, which is assumed to have the same elevation as the stack base.

When modelling in a region of flat terrain, no digital mapping of terrain will be necessary. However, in Ireland, areas of flat terrain will be quite rare and digital mapping of terrain may be necessary in many cases. Sensitivity studies conducted in New Zealand suggest that where terrain is 10% of stack height and is ignored, a 10% underestimation of peak concentration is likely to occur(28). Guidance from Alberta, Canada advises that digital terrain mapping should be undertaken where the terrain gradient is greater than 5%(37). In ADMS 4, guidance(38) suggests that terrain should be included if the gradient is greater than 10%. AERMAP(18) has defined significant terrain elevations as “all the terrain that is at or above a 10% slope from each and every receptor”. AERMAP uses this definition to define the controlling hill height for each receptor which is then used in AERMOD to calculate the critical dividing streamline height H_{crit}.

The above guidance does not take into account the effective stack height of the plume and may be excessively onerous for operators in certain circumstances. For example, based on a terrain gradient of 5%, all installations within 20km of Carrauntoohil, Kerry (1039 OD) would be required to model terrain covering a grid of at least 30km x 30km under the Alberta

guidance. It may however be reasonable to assume that terrain features 10-20km downwind will not be relevant to an installation with a modest effective stack height of, for example, 50m.

In order to allow for variations in effective stack height (actual stack height plus an additional height to allow for buoyancy), the recommendation in regards to terrain is outlined below.

In relation to ADMS 4:

- the complex terrain module (FLOWSTAR) should not be used unless hill slopes are greater than 1:10(38);

In relation to AERMOD:

- digital mapping of terrain should be conducted where terrain features are greater than 10% of the effective stack height within 5km of the stack (for effective stack heights of 100m or less);
- digital mapping of terrain should be conducted where the terrain features are greater than 10% of the effective stack height within 10km of the stack (for effective stack heights of greater than 100m);
- an estimate of the range of effective stack heights can be obtained from the SCREEN3 model (see Section 4.1).

Modelling Of Terrain In ADMS 4

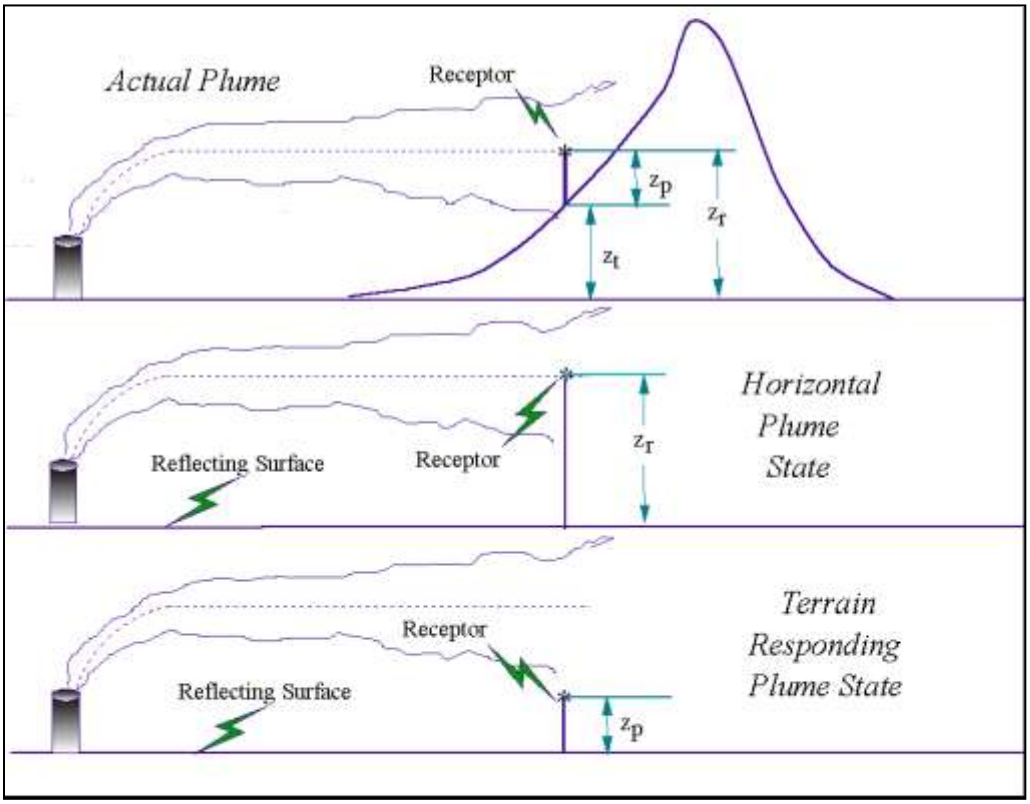
The modelling of terrain in ADMS 4 is conducted using the FLOWSTAR model(27) when the Froude number (which is a measure of atmospheric stability) is greater or equal to unity and using the dividing streamline concept when the Froude number is less than unity. The model has an additional algorithm for plumes released into an area of recirculating flow. The model calculates the flow and turbulence fields across the terrain and then adjusts the plume height and plume spread parameters previously calculated by the flat terrain model.

The FLOWSTAR model requires a terrain file (in X,Y,Z format of up to 5000 data points) and surface roughness information. The model assumes terrain slopes no greater than 1:3 and recommends that it should not be used unless hill slopes are greater than about 1:10(38).

Modelling Of Terrain In AERMOD

The modelling of terrain in AERMOD is performed using the concept of the dividing streamline(16). The height scale, h_C, derived from AERMAP, characterizes the height of the surrounding terrain that most dominates the flow in the vicinity of each receptor. This height scale is used by AERMOD to determine the dividing streamline height H_C.

The portion of the plume mass above and below the dividing streamline is then determined. That portion below the dividing streamline is assumed to impact directly on the terrain feature whereas the portion above the dividing streamline is assumed to be terrain-following and rise over the terrain as shown in **Figure 6.2**.



Note: Zt = terrain height at receptor, Zp = height of receptor above local ground, Zr = height of receptor above stack base elevation

Figure 6.2 AERMOD two-state approach: The total concentration predicted by AERMOD is the weighted sum of the two extreme possible plume states. (*taken from USEPA (2004) AERMOD: Description of Model Formulation*[(16)])

Terrain Downwash

Terrain downwash is defined by the USEPA as occurring when terrain features are greater than 40% of the Good Engineering Practice (GEP) stack height (see Section 6.3) within 800m of the stack[(39)]. In the presence of terrain downwash, the wind field upwind of the stack will be subjected to additional turbulence (similar to building downwash) which will tend to draw the plume downwards leading to higher ground level concentrations that would have occurred in the absence of the upwind terrain feature.

ADMS 4 can allow for terrain downwash using the FLOWSTAR model. However, AERMOD does not currently take upwind terrain features into account during modelling. Research literature[(40)] has suggested that values could be between 2 – 3 times higher under the presence of terrain downwash. This research study also indicated that terrain downwash and building downwash can jointly impact on the plume rise and enhance the downwash effect.

Receptor Grid Size & Resolution

Council Directive 2008/50/EC (Annex 3) has outlined the locations at which ambient air quality should be assessed for the protection of human health and ecosystems. The Directive states that no assessment should be conducted: (i) within an industrial installation (where health and safety legislation applies); (ii) in areas where the public do not have access and there is no fixed habitation, and (iii) on the carriageway of roads. The Directive also highlights that the assessment should be conducted over time periods which are significant in relation to the averaging period of the limit values. However, as a worst-case, air dispersion modelling is usually conducted at all locations outside of the site boundary of the applicant including within the site boundaries of other industrial installations.

In relation to impacts on vegetation and natural ecosystems, the Directive states that assessments should not be conducted within 20km of an agglomeration or within 5km of other built-up areas, industrial installations, motorways or major roads (> 50,000 AADT). The Directive additionally recommends that the assessment should be representative of the surrounding area of at least 1000 km^2. Where a sensitive environment, such as a Special Area of Conservation (SAC), Special Protection Areas (SPA) or National Heritage Areas (NHA), is located within these restricted areas, an assessment will still be required.

Air dispersion models will normally require a receptor grid at which ground-level concentrations can be calculated. The receptor grid may be either Cartesian or polar and either uniform or irregular. Cartesian grids have the advantage of equally spaced receptors irrespective of distance from the source and are generally preferred. Polar grids have good resolution near the source but poorer resolution away from the source, which may be the location of maximum ground level concentration for taller stacks.

The receptor grid should be large enough to ensure that the maximum ground-level concentration is captured. The grid size necessary will be project specific and will vary depending on stack height, buoyancy of the plume, geophysical factors and meteorological conditions. Depending on the results from initial model runs the resolution of the receptor grid may need to be adjusted to ensure sufficient resolution in the areas of maximum impact.

Point sources may require grids no greater than 3km x 3km for small non-buoyant stacks (i.e. a radius of 1.5km) whilst area sources and sources subjected to significant building downwash may require even smaller grid sizes. However, tall stacks with buoyant plumes are likely to need a minimum grid size of 20km x 20km centred at the source. In all cases, a model run using a low-resolution grid will help to identify the extent of the grid that will be necessary.

Grid resolution will be a compromise between computational efficiency and modelling accuracy. High grid resolution may lead to a higher maximum ground level concentration but at the cost of greater modelling run times. EU guidance indicates that assessment of industrial "hot-spots" should generally be at a resolution of no greater than 250m x 250m[(41)]. It is considered however that this resolution is too large for many of the smaller stacks being modelled at IPPC installation (e.g. 10 – 20 metres) and thus this should be counter-balanced by the need to identify worst-case concentrations within the modelling domain. Guidance suggests that an optimum grid resolution should be sought, such that any increase in grid resolution does not increase the maximum ground level concentration by greater than 10%[(28)].

Nesting of receptor grids can be performed with AERMOD, while ADMS 4 allows for variable Cartesian grids which perform the same function. The multi-tiered grid should have a fine resolution near the source (or near the point of maximum ground level concentration) with a progressively coarser grid as one moves away from this maximum. An example of such a grid is shown in **Figure 6.3**.

Where the maximum ground level concentration occurs in an area of complex terrain, a higher grid resolution (20m – 50m) may be warranted. Similarly, where the maximum ground level concentration occurs at the site boundary, a grid resolution of up to 10m may be warranted to ensure the peak concentration is adequately captured. No receptors however should be located within the property line as health and safety legislation (rather than ambient air quality standards) is applicable within the site.

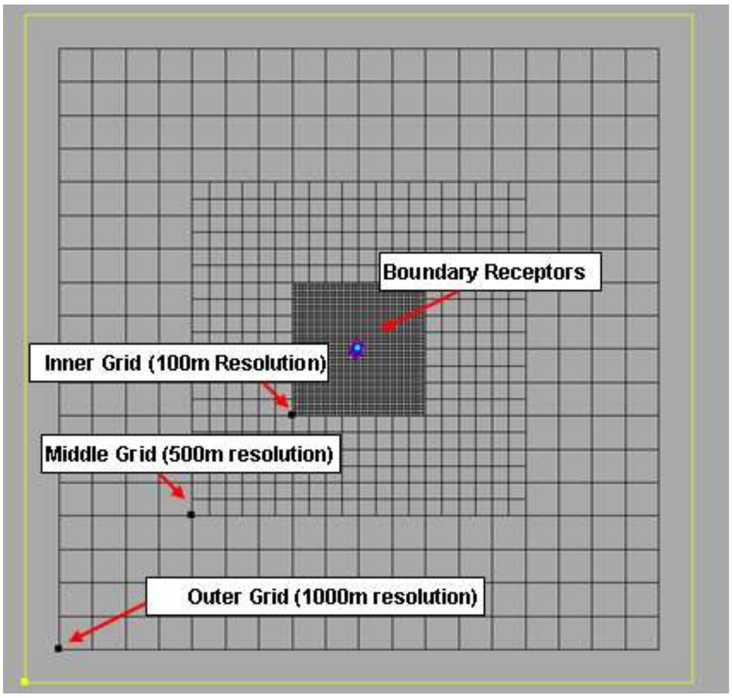


Figure 6.3 3-Tiered Nested Grid At 100m, 500m and 1000m resolution in additional to boundary receptors at 20m resolution.

Generally, the receptor height can be either zero or 1.5-1.8m (breathing height), with the selection of height in this range having no significant impact on the results. Where there are large buildings in the modelling domain with balconies, open windows or air intakes, flagpole receptors should be placed at these locations also.

BOX 2: Geophysical Data

The guidance in relation to geophysical data is as follows:

- Default or recommended surface parameters should be used in the meteorological files and as input into the air dispersion model.
- When modelling in urban areas, the urban option in the model should be invoked where applicable based on the model user manual.
- In order to allow for variations in effective stack height, the recommendation in regards to terrain is:
    - when using ADMS 4, the complex terrain module (FLOWSTAR) should not be used unless hill slopes are greater than 1:10;
    - when using AERMOD, digital mapping of terrain should be conducted where terrain features are greater than 10% of the effective stack height within 5km of the stack (for effective stack heights of 100m or less) or within 10km of the stack (for effective stack heights of greater than 100m);
- Cartesian grid sizes will vary depending on the characteristics of the sources being modelled. A model run using a low-resolution grid will help to identify the extent of the grid that will be necessary.

6.3 Building Downwash

When modelling emissions from an industrial installation it should be borne in mind that stacks which are relatively short can be subjected to additional turbulence, due to the presence of nearby buildings. Buildings are considered nearby if they are within five times the lesser of the building height or maximum projected building width (but not greater than 800m).

The USEPA has defined the "Good Engineering Practice" (GEP) stack height as:

> *"the height necessary to ensure that emissions from the stack do not result in excessive concentrations of any air pollutant in the immediate vicinity of the source as a result of atmospheric downwash, eddies or wakes which may be created by the source itself, nearby structures or nearby terrain obstacles."*[39]

The GEP stack height is defined by the USEPA as the building height plus 1.5 times the lesser of the building height or maximum projected building width. It is generally considered unlikely that building downwash will occur when stacks are at or greater than GEP.

When stacks are less than this height, building downwash will tend to occur as shown in **Figure 6.4**. As the wind approaches a building it is forced upwards and around the building leading to the formation of turbulent eddies. In the lee of the building these eddies will lead to downward mixing (reduced plume centreline and reduced plume rise) and the creation of a cavity zone (near wake) where re-circulation of the air can occur. Plumes released from short stacks may be entrained in this airflow leading to higher ground level concentrations than in the absence of the building.

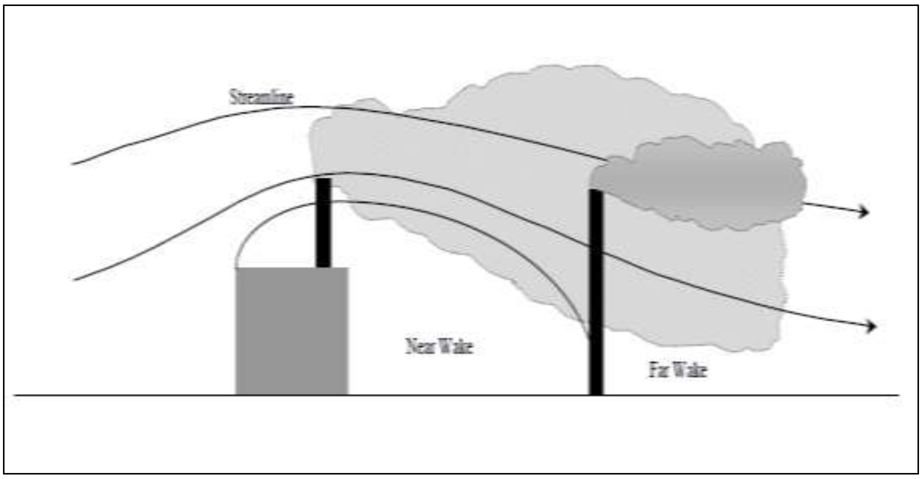


Figure 6.4 Schematic of building downwash for two identical plumes emitted at different locations (taken with permission from Schulman et al (2000)[42])

Building Downwash In ADMS 4

ADMS 4 uses the Buildings Effect Module to calculate the effect of building downwash on stack releases. In the near-wake the model derives a spatially mean concentration based on a box model and calculates the concentration in the near-wake based on the fraction of pollutant entrained into this zone. The model takes account of the stack location and allows for complete or partial entrainment in the near wake (cavity zone)[42]. The deflection of the mean streamlines above the near-wake is a function of building shape, orientation and source height. In relation to the main wake, which is the turbulent wake downwind of the recirculating flow region, a double plume concentration profile is used based on Gaussian concentration distributions. The main wake model uses the decay of the momentum wake to determine the mean streamline displacement[42].

The model requires the selection of one dominant building for each source or an effective building representing a group of closely spaced buildings or tanks[42]. The module does

caution in regards to the selection of building input information as the size of the near wake region and its effect on dispersion is sensitive to the dimensions of the effective building[42]. As the selection of the main building is at the user's discretion, where this is not clear, a sensitivity study should be undertaken to ensure the worst-case building(s) is selected.

Building Downwash In AERMOD

The Plume Rise Model Enhancements (PRIME) plume rise and building downwash algorithms have been incorporated into AERMOD. The building input processor BPIP-PRIME produces the parameters which are required in order to run PRIME. The model takes into account the position of each stack relative to each relevant building and the projected shape of each building for 36 wind directions (at 10º intervals). The model determines the change in plume centreline location with downwind distance based on the slope of the mean streamlines and coupled to a numerical plume rise model[43].

The model has been tested over the range of building width / building height ratios of 0.3 – 3.0 and found to agree quite well with observations. It should therefore be used with caution outside of this range. Caution should also be exercised when buildings are in the region of 40% of the stack height. Due to the nature of the PRIME algorithm, the module will be initiated when the building is exactly 40% of stack height but will not be activated when the building is 39.9% of the stack height. Large differences may be seen at this crossover and a sensitivity study of the model to small changes in building or stack heights is recommended when this occurs.

Porous Structures

Currently both ADMS 4 and AERMOD do not have the capability to model porous structures which are typically encountered in chemical or pharmaceutical installations. Research using fluid modelling has found that the flow in the vicinity of porous structures is much less affected than a similarly shaped solid structure[2,44]. However, as a worst-case it may be prudent to assume a solid structure until such time as an algorithm is developed to specifically model these structures.

BOX 3: Building Downwash

The guidance in relation to building downwash is as follows:

- Relevant nearby buildings which are 40% or greater of stack height should be included in the model and the model run with the appropriate building downwash algorithm.
- When buildings are within 1-2 metres of the 40% rule, a sensitivity study should be undertaken by increasing the building to 40% of the stack height and the model run with the relevant building downwash algorithm.

6.4 Source Parameters

Point sources (stacks or vents) are the most common source type from industrial installations. In order to model point sources an accurate determination of the following information will be required:

- Emission rate (typically in g/s) – emission rates are directly proportional to modelled concentration (for inert pollutants) and thus any errors in emission rates will feed directly through to the final result;

- Temperature of release (in K / ºC) — the exit temperature will be important in the determination of plume rise and thus errors in exit temperature for buoyant plumes may lead to significant errors in modelled results;

- Stack diameter (in m) – the inner diameter of the stack;

- Stack Height (in m) – this should be the height above the stack base elevation;

- Stack Coordinates (in m) – either in UTM, ITM or Irish Grid or using relative grid coordinates. Whichever co-ordinates are used they should be consistent across all input parameters (terrain, sources, buildings etc.);

- Stack exit velocity (in m/s) – this should be based on the actual conditions of release, i.e. actual temperature, moisture and oxygen content (if relevant) or stack exit volume flow rate (in m^3/s). (Any corrections for temperature, pressure, etc. should be applied separately to calculate mass emissions);

- Stack base elevation (in m) – important when terrain is a factor.

Emission Rate Determination

In assessing the impact from an existing or proposed installation, a worst-case approach is a prudent starting point. By ensuring that the impact from the installation is overestimated, compliance with the ambient air quality standards under these assumptions should ensure that the risk to health and the environment from the operation of the installation is minimal.

As an initial starting point, the point source(s) should be modelled at the IPPC or Waste Licensed concentration limit assuming continuous operations for 8760 hours/annum. When calculating the mass emission (in g/s) from a stack, the volume flow and emission concentration should be at the same temperature, oxygen content and moisture content (typically both normalised to 273K, dry and the reference oxygen content). However, when modelling, the actual stack exit velocity should be input to the model without correction for moisture, oxygen content or temperature (rather than normalised conditions). Full details of the issues relating to standardisation of concentrations and volume flows are given in Annex 1 of the EPA publication "*Air Guidance Note on the Implementation of I.S. EN 14181 (AG3)*"(45).

N.B. Particular attention should be paid to ensuring that appropriate units are used and appropriate corrections are applied to emissions data. Miscalculation of emission rates due to incorrect application of correction factors (e.g. for moisture, temperature, etc.) is a common problem noted in modelling studies submitted to the EPA. Attention should be paid to ensuring the appropriate corrections are applied and this should be clearly detailed in the modelling report.

The study should also investigate the effect of changing the volume flow from maximum operation (as specified in the licence) to average (or 75% of maximum) operation. Two conflicting factors are at play as the volume flow changes. Higher volume flows will increase the mass emission (in g/s) from the installation whilst also increasing the momentum associated with the released plume. In contrast, lowering the volume flow will reduce the mass emission from the installation but also reduce the plume momentum. As a result, modelling at the maximum volume flow rate (which maximises the mass emission) will not necessarily lead to the highest ground level concentration.

Under all circumstances, the installation may not contribute to an exceedance of the ambient air quality standards when operating at the maximum emission concentrations as outlined in the relevant IPPC or waste licence. Where a stack does not operate continuously, this can be taken into account in determining compliance with the licence.

In circumstances where it is useful to compare typical emissions with maximum emissions, emission rates can be refined based on the specifics of the industrial process. The emission rates can be modified based on the following considerations:

- For average periods greater than 1-hour, emission rates can be used which are consistent with the averaging period under consideration (i.e. 24-hour means can be compared to the highest 24-hour emission rate, annual means can be compared to the annual average emission rate).
- Where a Continuous Emission Monitoring System (CEMS) is installed, detailed variations in volume flow, temperature and concentration will allow an accurate estimation of emissions from the installation. Infrequent stack monitoring (on a quarterly to annual basis) will however be unlikely to give a good indication of the variability of the emission rate.
- When modelling mixtures of organic compounds derived from monitoring data, the calibration gas used in the monitoring/analysis (usually propane or toluene) should be specified. Monitoring data may need to be reported as carbon in order to compare with the appropriate licence limit value. Further information on the conversion and interpretation of organic compounds can be obtained from Annex 1 of the EPA publication "*Air Guidance Note on the Implementation of I.S. EN 14181 (AG3)*"[(45)].
- For all averaging periods, variable emission rates can be used where processes only operate for set periods of time (i.e. between 8 am – 5 pm or weekdays only).
- For some sources such as Open Cycle Gas Turbine (OCGT) and newer generation Combined Cycle Gas Turbine power plants which are designed to operate for short periods of time, compliance with long-term averages can be assessed using average emission rates. However, for one-hour means (such as the 99.8^{th}%ile NO_2 standard), modelling may need to assume that maximum emissions overlap with the worst-case meteorological conditions (despite being statistically very unlikely) and therefore modelling for a full year is appropriate. It should also be considered for sources subject to frequent start-up and shut-down whether emissions during these periods are significantly higher than under normal operations. Where emissions are significantly higher, they should be modelled based on the likely frequency of occurrence and factored to allow for the enhanced emission rate.
- Abnormal operations (such as the bypassing of an Air Pollution Control System (APCS)) should be considered where realistic. In order to model an abnormal operation, the emission rate under this scenario and the frequency of occurrence should be determined.

Specific Considerations

Detailed below are certain emission sources that are infrequently encountered and require specific consideration:

- Horizontal sources and point sources with rain caps have little or no initial vertical velocity. In order to correct for this, the USEPA has proposed that the stack exit velocity should be reduced to 0.001 m/s and an equivalent stack diameter calculated such that the buoyant plume is properly calculated. Recent versions of AERMOD (since Version 06341) have an inbuilt option for capped or horizontal stacks which suppresses the vertical momentum while the buoyancy of the plume is conserved without modifying the stack parameters.

- Area sources (such as waste water treatment ponds, biofilters) & volume sources (such as multiple vents and conveyor belts) may be present at some industrial installations. Difficulties arise in modelling these types of sources due to uncertainties in volumetric flow and emission rates. Specific guidance on how these should be modelled is given in the ADMS 4[21] and AERMOD[46] user manuals.

BOX 4: Source Parameters

The guidance in relation to source parameters is as follows:

- A conservative estimate of emission rates should be the starting point for the assessment.

- Under all circumstances, compliance with the ambient air quality standards must be achieved when operating at the maximum emission concentrations as outlined in the relevant IPPC or waste licence.

- The stack exit velocity should be calculated using actual operating conditions uncorrected for oxygen content, moisture or temperature.

- Mass flow (in g/s) must be calculated by multiplying the emission concentration by the volumetric flow rate, with both parameters referenced to the same conditions (temperature, pressure, moisture, oxygen content).

- Careful consideration of variations in emission rates, exit temperatures and volume flow will be necessary particularly where they are subject to significant variations such as frequent start-ups or bypassing of abatement systems.

- Specific sources such as area or volume sources or sources with little momentum should be modelled in line with the model user manuals.

6.5 Background Concentrations

When modelling the release of pollutants from an industrial installation, it is important to consider whether the specific pollutants are already present within the modelling domain and at what concentration. The process contribution (PC) from industrial sources should always be added to the appropriate background concentration (BC) in order to obtain the predicted environmental concentration (PEC)[23].

For pollutants regulated under ambient air quality legislation (such as NO_2, SO_2, PM_{10}, CO and benzene) sufficient information should be available from a range of representative monitoring stations operated by the EPA or local authority stations[47,48] either within the modelling domain or at a location which would be expected to be exposed to similar levels of

these pollutants. To ensure consistency, fully validated EPA data should be used where available in preference to site specific monitoring data for those pollutants outlined above. The selection of the appropriate value should be based on either an average of the appropriate zonal concentrations or the use of the worst case value.

For pollutants not routinely monitored by the EPA, such as acid gases (HCl, HF), heavy metals, dioxins & furans, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs) and various volatile organic compounds (VOCs) fully validated and quality assured (QA) data from other sources may be used with caution. The UK DEFRA[49] operates extensive monitoring networks for many of these compounds although care should be taken when using this source to ensure that the data has been captured in a similar environment to the region of interest.

The main considerations relating to background concentrations are:

- **Is existing data adequate or will site-specific monitoring be required?**

As part of the implementation of the Framework Directive on Air Quality (1996/62/EC), four air quality zones have been defined in Ireland for air quality management and assessment purposes[48]. Dublin is defined as Zone A and Cork as Zone B. Zone C is composed of 21 towns with a population of greater than 15,000. The remainder of the country, which represents rural Ireland but also includes all towns with a population of less than 15,000, is defined as Zone D. It is reasonable to assume that if monitoring data is available in a Zone C urban background location that this information would also be broadly representative of other urban background locations in Zone C locations although each scenario should be assessed on an individual basis to ensure that this approach is appropriate. Likewise, data for suburban Dublin should be representative of other suburbs of Dublin. In order to allow for local factors, meteorological variability and anomalies when sourcing background data from stations outside of the modelling domain, an average of at least two and preferably more representative stations should be used. Similarly, the data should be averaged over the most recent 2-3 years available.

- **If site-specific monitoring is required, how many monitoring locations and over what time periods (including seasonal effects) will the monitoring be required?**

Ambient air quality standards are usually expressed in terms of either annual means or short-term maximum (1-hr or 24-hr) expressed in terms of a percentile over a calendar year. It is therefore necessary to monitor for a minimum of a calendar year in order to directly determine whether existing ambient air quality is in compliance with the air quality standards at a particular location. However, it is possible to gain useful information from much shorter survey periods. Guidance is available from the UK DEFRA[50] in relation to estimating the long-term (annual) averages from a shorter-term monitoring survey as outlined in **Appendix E**.

The main aim of the baseline monitoring programme will be to determine existing background levels of pollutants. The monitoring programme may use diffusion tubes to obtain cost-effective spatial distributions of relevant pollutants such as NO_2, SO_2 and benzene. Monitoring however, is not an effective method to obtain information on the impact of an existing industrial installation, particularly when emissions are mainly from stacks. Modelling will be required in order to adequately characterise these emissions[41].

The number of monitoring stations required will be dependent on the size of the modelling domain, the number and variety of sources in the domain and the size and scale of the proposed installation. In general, diffusion tube monitoring for NO_2, SO_2 and benzene (or BTEX) can be conveniently undertaken at 5-10 locations within the domain whereas monitoring using reference equipment (type-approved chemiluminescent analysers for NO_X, type-approved gravimetric analysers for $PM_{10}/PM_{2.5}$) will normally be undertaken at one or, at most, two locations. Reference instruments are those specified by the EPA.

- **What is the acceptable accuracy of the background concentration data and is diffusion tube data sufficiently accurate?**

When site-specific monitoring is undertaken, the choice of sampling will dictate the accuracy of the data. Continuous analysers (such as NO_X chemiluminescent analyser) when operated correctly are considered to be accurate to ± 10% whilst diffusion tubes will be accurate to, at best, ± 20%[(50)]. Where background levels are already approaching the ambient air quality standards and may be critical to the assessment, continuous analysers are to be preferred. In many cases though background levels will be well below 50% of the ambient air quality standards and diffusion tube monitoring will be adequate.

- **Should existing maximum background pollutant levels be combined with maximum predicted levels and are they co-located or likely to occur under the same meteorological conditions?**

It is unlikely that the maximum measured short-term background concentrations will overlap spatially with the maximum predicted process concentration. However, the spatial availability of background data may be limited and thus it may be prudent to assume that the highest background data that is available within the modelling domain overlaps spatially with the process contribution, which is consistent with the worst-case approach to the assessment.

In relation to overlap on a temporal basis, background concentrations (which are usually derived from road traffic and home heating) will generally peak during the morning and evening rush hour and will be greatest during periods of stable atmospheric conditions. In relation to point sources, the conditions that lead to the peak concentration can be confirmed by an analysis of the meteorological conditions at the time of the occurrence. Where peaks occur during highly unstable conditions (which may be likely for tall stacks) it may be reasonable to use average background levels rather than peak background levels. However, where modelling results suggest peaking occurs during stable, inversion conditions the combination of maximum background plus maximum process conditions will need to be assumed. The UK DEFRA[(50)] has outlined a methodology to combine short-term peak concentrations with background concentrations as outlined in **Appendix E**.

BOX 5: Background Concentrations

The guidance in relation to background concentrations is as follows:

- The appropriate background concentration (BC) should always be added to the process contribution (PC) in order to obtain the predicted environmental concentration (PEC) with which compliance with the ambient air quality standards can be determined.

- All available sources of background data should be reviewed for suitability prior to initiating a site-specific monitoring programme.

- Site-specific background surveys should typically be at least 3 months. Guidance on extrapolating the survey data to annual means should be used.

- Available methodologies should be consulted to determine how best to add short-term background and process contributions.

6.6 Cumulative Assessments

When modelling the release of pollutants from an industrial installation, consideration should be given to the presence of other significant industrial installations within the modelling domain. As a first step, a review of IPPC or Waste Licensed installations should be

undertaken using the EPA mapping tool[(51)]. Where licensed installations are present, the licence should be reviewed in order to determine whether the existing installation has any major air emission sources and if so which particular pollutants are being released.

Once an existing nearby air emission point source has been identified, a methodology is required to determine whether this source needs to be included in the air dispersion modelling assessment and if so, which pollutants should be included. Once this assessment is undertaken, a further methodology is required to determine whether the cumulative impact arising is significant. A recommended approach when undertaking cumulative impact assessments is outlined in **Appendix F**.

BOX 6: Cumulative Impact Assessments

The guidance in relation to cumulative assessment is as follows:

- Where a nearby installation emits the same pollutant as the applicant installation, both at a significant level, a cumulative impact assessment may be necessary.
- The approach outlined in **Figure A2 (Appendix F)** should be followed to determine whether the cumulative impact arising is significant.

6.7 Treatment Of Deposition

Modelling of deposition may be necessary in order to determine the impact of pollutants in the terrestrial environment or as part of a human health or ecological risk assessment study.

Wet deposition of both particulate and gaseous pollutants can occur mainly as a result of precipitation. Dry deposition is also possible for both particulate and gaseous pollutants by means of various processes including gravitational settling, Brownian motion and inertial impaction[(52)]. Depletion of the plume will also occur as a result of both wet and dry deposition as a function of downwind distance. Guidance on modelling both wet and dry deposition is outlined in **Appendix G**.

BOX 7: Modelling of Deposition

The guidance in relation to modelling of deposition is as follows:

- Modelling of deposition should be undertaken using the default or recommended parameters as outlined in the relevant modelling documentation.
- Modelling of wet deposition will require hourly precipitation data (in mm/hr) which is available from Met Eireann.

6.8 NO_2/NO_x Chemistry

Nitrogen dioxide (NO_2) has been a regulated pollutant for many years in contrast to nitric oxide (NO), which is not a regulated pollutant. Council Directive 2008/50/EC recently reaffirmed the applicable one-hour limit value (that may be exceeded no more than 18 times in a calendar year) and an annual limit value for NO_2.

During combustion processes, a mixture of both nitric oxide and nitrogen dioxide (termed NO_X) is released and once released a series of complex chemical reactions takes place over

time periods varying from seconds to days during which a portion of the nitrogen oxide is converted to nitrogen dioxide. Guidance on NO_2/NO_X modelling is outlined in **Appendix H**.

BOX 8: Treatment Of NO_2/NO_X Chemistry

The guidance in relation to the NO_2/NO_X chemistry is as follows:

- Screening modelling of NO_2/NO_X chemistry should use the following default factors:
  - a default annual NO_2/NO_X ratio of 1.00,
  - a default 1-hour NO_2/NO_X ratio of 0.50.
- Detailed modelling of NO_2/NO_X chemistry should use the PVMRM method in AERMOD or the ADMS 4 chemistry module.
- A site-specific ratio at the point of maximum concentration may be used if extensive continuous monitoring data (one-year or greater) is available at this location. However, the site-specific ratio will only be valid for locations which are a similar distance from the source as the monitoring station.

6.9 Treatment Of Odour

Modelling of odour may be required when an industrial installation releases odours which are likely to cause annoyance. Examples of such industries include rendering installations, composting, landfills, asphalt production, chemical manufacture and intensive livestock industries. Aspects of modelling relevant to odour are outlined in **Appendix I**. Relevant odour guidance documents[53-57] should also be consulted as odour modelling is only one aspect which needs to be considered when undertaking an odour impact assessment.

BOX 9: Odour Modelling

The guidance in relation to odour modelling is as follows:

- Modelling should be undertaken using a gridded receptor network and separately at specific sensitive receptors with results reported for both scenarios.
- For existing installations, olfactometry should be undertaken in order to determine suitable odour emission rates. Monitoring should be carried out at worst case operational conditions.
- The modelled odour concentration at all sensitive receptors near the installation should be compared to the odour criteria outlined in **Appendix I**.
- Monitoring of background odours is inappropriate and cannot be added to modelled odour concentrations.

6.10 Model Versions / Regulatory Options

Air dispersion models are continuously in a state of development. The ADMS model was originally developed in 1992 and has been revised substantially since then. The current version (ADMS 4) includes some recent scientific advances as well as expanding the range of

options that are available in the model. Similarly AERMOD, which dates from 1996, has been updated on a regular basis. The current USEPA regulatory version is termed AERMOD 09292 (09292 refers to the year and the Julian date) and now includes options relating to dry and wet deposition, PRIME building downwash, modelling of NO_X using the PVMRM methodology and options on modelling rain capped and horizontal stacks. AERMOD pre-processors (AERMAP (current version 09040) and AERMET (current version 06341)) are also regularly updated.

Importantly, updated model versions invariably include bug fixes of earlier versions and thus it is imperative that modellers should use the most recent model versions as they are released. The relevant websites should be checked on a regular basis to confirm that the model version being used is the most current:

AERMOD - http://www.epa.gov/scram001/dispersion_prefrec.htm#aermod
ADMS - http://www.cerc.co.uk/software/index.htm

The USEPA has outlined detailed guidelines in relation to the use of AERMOD for regulatory applications. The EPA recommends the use of the regulatory options when running AERMOD. If a modeller wishes to use a non-regulatory option (such as no stack-tip downwash or the PVMRM options for the NO_2/NO_X conversion ratio) justification for the approach should be given to the EPA and agreed prior to modelling.

In relation to ADMS 4, there are no regulatory options as such although the ADMS 4 user manual and technical guidance documents outline in detail how and for what purpose the model should be used. Where non-default options are used in ADMS 4, justification for the approach should be given to the EPA and agreed prior to modelling.

BOX 10: Model Versions / Regulatory Options

The guidance in relation to model versions / regulatory options is as follows:

- The most recent model version available should always be used.
- The model should be run using the applicable regulatory options or default options. Where non-default options are used, justification for the approach should be given to the EPA and agreed prior to modelling.

6.11 Model Accuracy And Sensitivity Studies

Models are subject to both reducible and inherent (non-reducible) uncertainties. The first reducible uncertainty (and also the most important for the modeller) is within the set of model input parameters. The input parameters which can be prone to error and are of most concern are:

- Errors in the emission rate can lead to large errors in the modelling results. As a result, it is prudent to assume continuous operation (8760 hours/annum) at the maximum allowable emission rate as outlined in the IPPC or waste licence. Where emission rates vary on an hourly, daily or seasonal basis, the frequency of operation can be reduced to replicate this when comparing to annual mean limit values (though not for short-term limit values);
- Inappropriate meteorological data – selecting an inappropriate meteorological station can lead to error particularly where the mean wind speed varies significantly between the source and meteorological station;
- Ignoring terrain features - terrain features can lead to significantly higher ambient concentrations compared to flat terrain. Where the terrain is greater than 10% of the effective stack height, digital terrain data will be required;

- Ignoring building downwash – where the stack height is less than the GEP stack height, building downwash will need to be considered. Building downwash will typically give significantly higher ambient concentrations relative to a stack release not subjected to building downwash.

A second reducible uncertainty is the model formulation that may be based on inadequate or incorrect physics of the atmosphere. The uncertainty in the model formulation is referred to as “model accuracy” by the USEPA and has been the focus of many research studies. The conclusions drawn by the EPA from these studies are[13]:

- Models are more reliable for estimating longer time-averaged concentrations than for estimating short-term concentrations at specific locations;

- The models are reasonably reliable in estimating the magnitude of highest concentrations occurring sometime, somewhere within an area (errors in highest estimated concentrations of ± 10 to 40 percent are found to be typical);

- Estimates of concentrations that occur at a specific time and site are poorly correlated with actually observed concentrations and are much less reliable;

- Uncertainty of five to ten degrees in the measured wind direction, which transports the plume, can result in concentration errors of 20 to 70 percent for a particular time and location, depending on stability and station location. Such uncertainties do not indicate that an estimated concentration does not occur, only that the precise time and locations are in doubt;

- Inherent uncertainty is due to the random nature of the turbulent field through which dispersion takes place. The USEPA has estimated that even for a perfect model the inherent uncertainty alone may account for a typical range of variation in concentrations of as much as ± 50%.

The model accuracy should be recognised in the assessment and an appropriate “window” reserved between the predicted environmental concentration (PEC) (background (BC) plus process contribution (PC)) and the ambient air quality standard (AQS). Typically the process contribution under maximum operations should be no more than two-thirds (66.7%) of the ambient air quality standard and less than this where background levels account for a significant fraction of the ambient air quality standard based on the formula:

Maximum Allowable PC = (AQS – BC) / 1.5

The above formula allows for the inherent uncertainty in air dispersion modelling (± 50% of the PC) to be taken into account. This margin of uncertainty when added to the process contribution will not lead to an exceedence of the ambient air quality standard.

Sensitivity Study

In order to test the sensitivity of the model to the most important input parameters, a sensitivity study should be considered particularly where predicted environmental concentrations (PEC) approach the ambient limit values (taking into account the margin of error in the modelling assessment). Some of the possible studies which can be conducted are outlined below in **Table 6.2**. Depending on the model scenario not all of the sensitivity studies will be necessary, but should include those input parameters where there is an uncertainty in the data available:

Parameter	Sensitivity Study
Meteorological Data	At least 3 years of meteorological data should be modelled with all years reported and the assessment based on the worst-case year(s) Data from a second nearby representative meteorological station may be useful where the applicability of the station used in the assessment is in doubt (modelled for the same time period and results compared)
Volume Flow	Maximum licensed operations x maximum volume flow Maximum licensed operations x 75% of maximum volume flow
Terrain	Model run with digital terrain Model run with flat terrain
Building Downwash	Model run with building downwash Model run without building downwash Selection of an alternative “Main Building” where this selection is ambiguous (applies to ADMS only)
Surface Parameters (Surface Roughness, Albedo, Bowen Ratio, Priestley-Taylor)	Model run with default parameter (e.g. S.R. of 1m for urban area) Model run with non-default parameter (e.g. S.R. of 0.5m or 2m instead)
Urban Option	The model should be checked for the sensitivity of this parameter (applies to AERMOD only)
Stack Height(s)	Where the model is being used to design the stack height(s), various stack heights should be investigated and results displayed
Model Comparison	Under certain circumstances for particularly complex problems, a comparison between models may be warranted. Such a study could include AERMOD / ADMS 4 vs CALPUFF or AERMOD vs ADMS 4 in areas of complex terrain or for installations with tall stacks at coastal locations

Table 6.2 Range Of Possible Sensitivity Studies To Be Considered

The results from the sensitivity studies should be carefully reviewed to check if there are significant variations in the modelled results due to changes in any specific input parameter. Where results are approaching or exceeding the ambient limit values due to changes in one or more of the model input parameters, a closer examination of the selected parameter will be necessary. This may necessitate a more detailed assessment or a more cautious approach to the issue of stack height.

BOX 11: Model Accuracy And Sensitivity Studies

The guidance in relation to model accuracy & sensitivity studies is as follows:

- All input parameters should be confirmed and justified where necessary. The data should additionally be checked by a co-worker as part of a QA system.
- The model accuracy should be recognised and an appropriate "window" reserved between the predicted environmental concentration (background plus process contribution) and the ambient air quality standard. Typically the process contribution under maximum operations should be no more than two-thirds of the ambient air quality standard and less than this where background levels account for a significant fraction of the ambient air quality standard based on the formula:

Maximum Allowable PC = (AQS – BC) / 1.5

- When modelling to determine stack height for an installation, a screening model will be inappropriate. In determining stack heights an appropriate assessment will normally require the use of either ADMS 4 or AERMOD (and using detailed modelling options for NO_2/NO_X).
- A sensitivity study should be undertaken in cases where the predicted environmental concentration approaches the ambient limit value. Some or all of the parameters outlined in **Table 6.2** may need to be considered in these cases.

6.12 Reporting Requirements

The air dispersion modelling report would typically address the following:

- aims of the study;
- details on the relevant regulatory regime and the appropriate ambient air quality standards. The appropriate air quality standards in the first instance should be the current (or future in the case of $PM_{2.5}$) EU ambient standards (see **Appendix K**). Where no EU air quality standard exists, relevant statutory standards from other EU countries such as the UK, Germany or Denmark should be used. Where no standards are identified from these sources WHO guidelines, US standards or standards derived from health & safety limit values may be referenced;
- discussion on the existing environment including background concentrations of pollutants, meteorology and geophysical considerations (terrain, land use);
- identification and location of sensitive receptors;
- summary of meteorological data, average and range of wind speeds, number of calm hours, etc;
- local designated habitats;
- building and source information including building elevations, heights, layout; sources process information (exit velocity, temperature, stack diameter, volume flow, emission rates of pollutants, information on frequency, duration and magnitude of emissions), source location (Irish Grid, ITM or UTM);
- emission data – source of data, accuracy and variability of data.

- stack height information – is the study being used to design the stack height? Is the stack height GEP or subjected to building downwash?

- receptor grid location and resolution, size & nesting options, sensitive receptors, boundary receptors, flagpole receptors if relevant;

- surface parameters used in the dispersion model (surface roughness, albedo, Bowen ratio, modified Taylor-Priestly parameter);

- model selection methodology and assumptions, discussions in regards to regulatory options, defaults or non-defaults, screening assumptions or detailed analysis;

- model results including in tabular format (an appropriate degree of precision (normally no more than two or at most three significant figures) in reporting of results should be used):

  - process contributions for each modelled year for each relevant averaging period, background concentrations used for each averaging period;
  - modelled results for typical operations, maximum, abnormal, start-up etc. where relevant;
  - predicted ambient concentrations both in absolute terms and as a percentage of the ambient air quality standards;
  - summary of meteorological data including missing & calm hours (before filling), missing data after filling, conditions which lead to maximum concentrations;
  - summary of results from any sensitivity studies which were conducted.

- model results in graphical format such as:

  - contour plots for each pollutant and averaging period appropriate to the ambient air quality standards;
  - site plan showing buildings, sources, boundary, receptor grid;
  - 3-D terrain plot and land use plot if relevant;
  - wind rose plots for all meteorological years modelled.

- computer files may include:

  - model input and output files for all scenarios including sensitivity studies;
  - building downwash files;
  - meteorological files;
  - terrain files;
  - soft copies of contour plots (e.g. surfer files) and CAD drawings of site;
  - all other relevant files used in the air dispersion model.

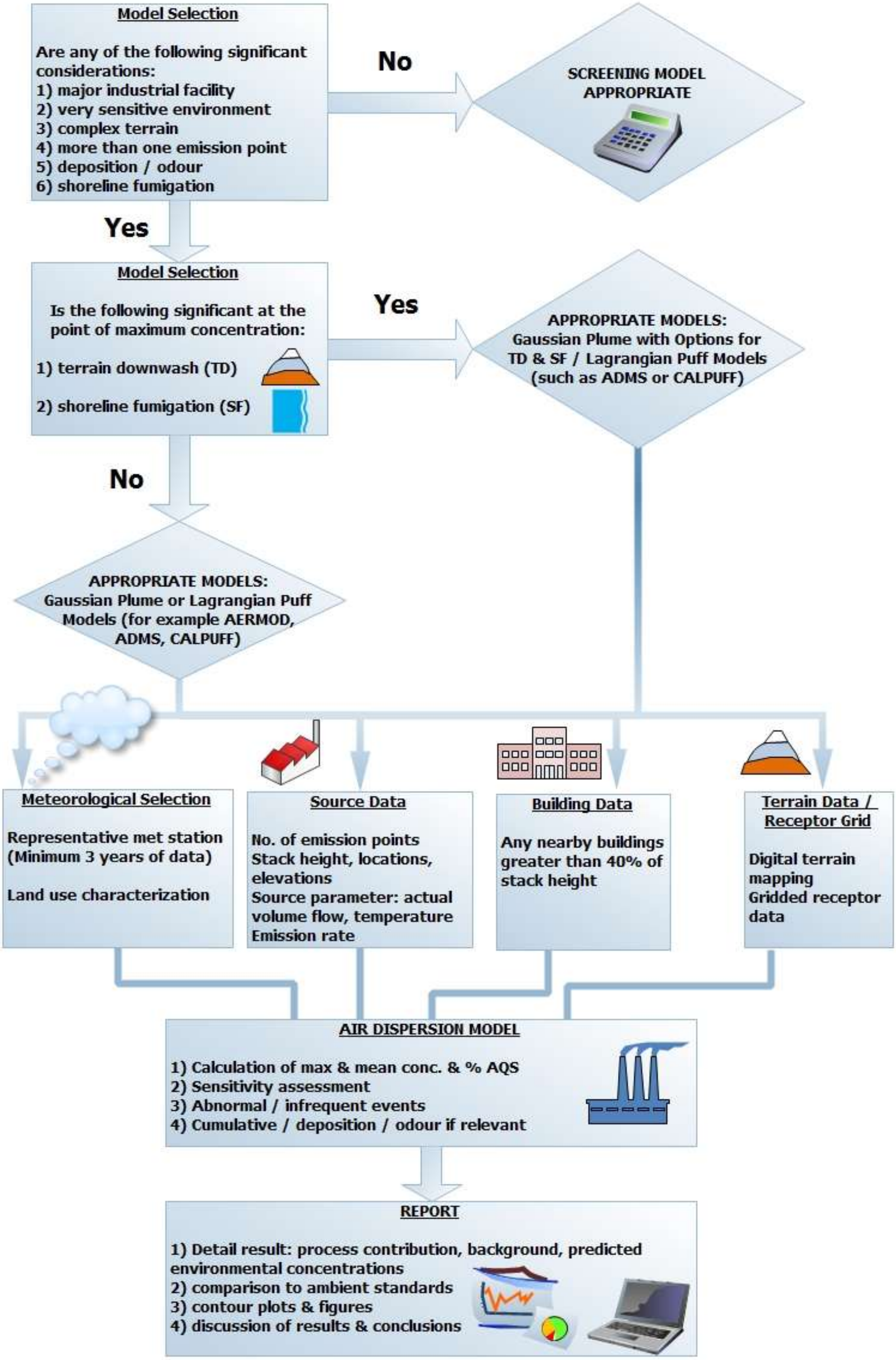
- model discussion of results including:

  - model results compared to the ambient air quality standards taking into account model accuracy;
  - discussion of the location of worst-case receptors;
  - meteorological conditions under which worst-case results occur;
  - significance of building downwash or terrain in the modelling.

The modelling report should be sufficiently detailed to allow the regulator to determine whether the study has been undertaken correctly. It should also be sufficiently detailed that an independent model user could undertake the study based on the information contained in the modelling report (and associated computer files).

7.0 SUMMARY

7.1 Air Dispersion Modelling Assessment - Summary Flowchart



7.2 Conclusions

The aim of this guidance note is to provide clear and robust methodologies, which should be followed when undertaking an air dispersion modelling assessment of an industrial installation. The methodologies presented should be viewed as best practice and are necessary in order to ensure that the assessments meet the desired level of accuracy and are of a uniform standard.

The guidance note has focussed on the practical issues that face modellers when undertaking an assessment. Practical issues include the choice of model, the selection of representative meteorological data and approaches to incorporating background concentrations into the assessment. The guidance note has not focussed on the theoretical aspects of modelling which is not to be taken as a sign that this feature of modelling is unimportant. The theory of air dispersion modelling is fundamental to the successful adoption and use of any air dispersion model. However, the theoretical details of air dispersion modelling are widely available in many excellent textbooks and all models recommended in this guidance have produced detailed descriptions of their model formulation. Any theoretical limitations of the various models should be understood whilst the detailed model formulations of the models should be read as a matter of course before using any model.

Not all guidance will be applicable to every modelling assessment. Likewise, there will be circumstances where there will be a need to stray away from the methodologies outlined here. When this is the case, the modelling report should clearly outline why there is a need to adopt a different approach and to show that the adopted approach has similar or better scientific justification. Moreover, the approach should be likely to lead to results of a similar or greater accuracy than the default methodologies. Where the modeller is uncertain about the appropriateness of any aspect of the modelling assessment, it is advisable to discuss the modelling approach with the EPA prior to carrying out the assessment.

Dispersion modelling is changing rapidly particularly in regards to computer resources. Due to the rapid advances in the speed of personal computers, models which a few years ago required mid-range computers, such as CALMET/CALPUFF, can now be operated successfully on desktops. It is likely that some of the recommendations outlined in this document will alter over time and all modellers should keep abreast of any amended guidance from regulators and model developers.

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APPENDIX A – Summary of Dispersion Model Features

A summary of the theory behind the dispersion calculations and a summary of the input / output options for each of the screening and advanced dispersion models commonly used in Ireland are provided below.

SCREEN3

SCREEN3 is a steady-state Gaussian plume model which uses worst-case meteorological data to predict ambient pollutant concentrations resulting from single continuous emission sources[9]. Key features of the model include:

- Briggs plume rise calculations;
- Boundary layer characterised using Pasquill-Gifford (P-G) stability categories;
- Gaussian dispersion equations used;
- Building downwash effects of single building included using the methods of Hosker[58] and Schulman-Scire[59] Note 1
- Simple, elevated or complex terrain options based on the following definitions:
  - *Complex*: Terrain elevations exceed stack height;
  - *Simple elevated*: Terrain elevations are above stack base but below stack height;
  - *Simple*: Terrain heights do not exceed the stack base elevation;
- Receptor locations set using discrete distances or an array option;
- Worst-case meteorology modelled using a range of P-G stability classes and wind speeds;
- Urban / rural land use option for dispersion calculations Note 2;
- Deposition modelling not included;
- Option for modelling inversion-breakup fumigation in rural areas;
- Option for shoreline fumigation at inland rural sites with a stack height ≥10m and within 3km from a large body of water;
- Atmospheric chemistry not included;
- Predicts 1-hour (simple terrain) or 24-hour (complex terrain) concentrations. Short-term results can be converted to long-term averages using adjustment factors provided in the USEPA Screening Procedures document[11]. Percentiles not determined;
- Output in the form of a text file giving full input data and maximum predicted concentrations for all calculation procedures selected.

ADMS-SCREEN

ADMS-Screen is a Gaussian type steady-state plume model which uses worst-case and internal meteorological data to predict the ambient pollutant concentrations resulting from single continuous point sources[14]. Key features of the model include:

- Plume rise calculated using an integral model which solves the conservation equations for mass, momentum and heat;
- Boundary layer described using similarity theory and scaling factors, and is characterised by the layer depth and Obukhov length;
- Both Gaussian (for stable & neutral boundary layer) and skewed Gaussian (for convective boundary layer) dispersion equations used;
- Building downwash effects of single building included;
- Only simple terrain modelled;
- Receptor locations set as follows:
  - *Short-term calculations:* Output reported at 25 evenly spaced downstream receptors out to user-defined maximum distance;
  - *Long-term calculations:* Output reported on a regular Cartesian grid of 21 × 21 points out to user-defined maximum distance;
- Internal meteorological data used as follows:
  - *Short-term calculations:* Seven worst-case meteorological conditions used;

Note 1 The worst-case results from both options should be used.

Note 2 The selection of urban or rural land use option should be made using the procedure outlined in Section 6.2.

  - *Long-term calculations:* Internal meteorological data file selected based on site location. File contains a wide range of meteorological conditions based on UK Met Office data. No data available for Republic of Ireland;
- Land use incorporated into user selection of appropriate roughness length;
- Deposition modelling not included;
- Modelling of coastal fumigation not included;
- Atmospheric chemistry not included;
- Predicts hourly, 24-hour and annual average concentrations and percentiles. Compares concentrations directly with EU limit values for user-defined pollutants;
- Output in form of a range of file types for analysis and plotting in spreadsheet and graphics software packages.

AERSCREEN

AERSCREEN is a steady-state Gaussian plume model which uses worst-case meteorological data to predict the ambient pollutant concentrations resulting from single continuous emission sources(12). Key features of the model include:

- Plume rise in the convective boundary layer accounts for momentum and buoyancy effects using Briggs formulation. In the stable boundary layer the calculations are modified to account for the decrease in plume buoyancy as the plume rises(12);
- Boundary layer characterised using similarity profiling relationships between boundary layer parameters, measured meteorological data, and other site-specific information;
- Gaussian dispersion equations used for the stable boundary layer. Both Gaussian (horizontal distribution) and skewed Gaussian (vertical distribution) dispersion equations used for the convective boundary layer;
- Building downwash effects of single building included. Calculated using the PRIME algorithm(43);
- Complex terrain modelled using a dividing streamline approach. AERMAP pre-processor used to define terrain elevations and hill height scales for each receptor. AERMAP requires a digital elevation model (DEM) input file;
- Receptor locations set as follows:
  - *Flat terrain / no building downwash:* Receptors fixed at 25m intervals out to 5 km downwind of source;
  - *Flat terrain / building downwash:* Receptors fixed along 10 degree radials at 25m intervals out to 5 km from source;
  - *Complex terrain with or without building downwash:* Receptors fixed along 10 degree radials at 25m intervals or 200 receptors out to 5 km from source;
- Worst-case meteorological data used based on user-defined parameters;
- Land use incorporated into model by user-defined surface characteristics;
- Deposition modelling not included;
- Modelling of coastal fumigation not included;
- Atmospheric chemistry not included;
- Predicts 1-hour concentrations only. Short-term results are converted to long-term averages using adjustment factors. Percentiles not determined;
- Output in form of a range of file types for analysis and plotting in spreadsheet and graphics software packages.

AERMOD

AERMOD is a steady-state Gaussian plume model which can simulate dispersion from multiple sources using up-to-date concepts regarding boundary layer characterisation and dispersion(13,16). Key features of the model include:

- Plume rise in the convective boundary layer accounts for momentum and buoyancy effects using Briggs formulation. In the stable boundary layer the calculations are modified to account for the decrease in plume buoyancy as the plume rises(16);
- Boundary layer characterised using similarity profiling relationships between boundary layer parameters, measured meteorological data, and other site-specific information;

- Gaussian dispersion equations used for the stable boundary layer. Both Gaussian (horizontal distribution) and skewed Gaussian (vertical distribution) dispersion equations used for the convective boundary layer.
- Two meteorological input data files used, which are prepared by the AERMET pre-processor:
  - *Surface file:* Contains surface meteorological data and scalar parameters;
  - *Profile file:* Consists of meteorological data taken at more than one height (for use in processing on-site data only). In the absence of on-site data, the 10m meteorological data from the surface file is used.
- Receptor locations set using four options as set out below. Multiple receptor networks can be defined in a single model run:
  - *Discrete receptors:* Individual receptor locations set by the user;
  - *Cartesian Grid:* Gridded Cartesian array of receptors, each defined by x (east-west) and y (north-south) coordinates;
  - *Polar Grid:* Gridded Polar array of receptors, each defined by distance and angle from grid centre;
  - *Boundary Receptors:* Individual boundary receptor locations set by the user. Prediction of concentrations within the boundary can be turned off by the user.
- Complex terrain modelled using a dividing streamline approach. AERMAP pre-processor used to define terrain elevations and hill height scales for each receptor. AERMAP requires a digital elevation model (DEM) input file;
- Land use incorporated into meteorological pre-processing by AERMET;
- Building downwash effects calculated using the PRIME algorithm(43);
- Dry and wet deposition modelling of both gases and particulates can be performed;
- Modelling of coastal fumigation not included;
- Atmospheric chemistry generally not included. However, USEPA “non-regulatory” options are provided to describe NO_X chemistry using the Plume Volume Molar Ratio Method (PVMRM) and the Ozone Limiting Method (OLM)(13);
- Predicts range of short and long-term concentrations from 1-hour to annual average. Post-processing to calculate user-defined percentiles. Also calculates short and long-term deposition flux;
- Output in form of a range of file types for analysis and plotting in spreadsheet and graphics software packages.

ADMS 4

ADMS 4 is an advanced steady-state Gaussian type plume model which can simulate dispersion from multiple sources(21). Key features of the model include:

- Plume rise calculated using an integral model which solves the conservation equations for mass, momentum and heat;
- Boundary layer described using similarity theory and scaling factors and is characterised by the layer depth and Obukhov length;
- Both Gaussian (for stable & neutral boundary layer) and skewed Gaussian (for convective boundary layer) dispersion equations used;
- Meteorological input data used for pre-processing can be of the following types:
  - Hourly sequential meteorological data;
  - Statistical records of meteorological data;
  - Set of unrelated (non-sequential, non-statistical) meteorological conditions;
- Receptor locations set using three options set out below. Multiple receptor networks can be defined for a single model run:
  - *Specified points:* Individual receptor locations set by the user;
  - *Cartesian Grid:* Regular or variable Cartesian array of receptors, each defined by x (east-west) and y (north-south) coordinates;
  - *Polar Grid:* Regular or variable polar array of receptors, each defined by distance and angle from grid centre;
- Complex terrain is modelled using two calculation methods:
  - *Stable conditions:* Calculation of flow over and around the terrain;
  - *Convective, neutral and moderately stable conditions:* Calculation of flow field and turbulence parameters using the FLOWSTAR model;

- Surface parameters which are reflective of land use category are incorporated into the meteorological inputs;
- Building downwash effects included. Calculated using internal building effects module;
- Dry and wet deposition modelling of both gases and particulates can be performed;
- Coastline module capable of modelling coastal fumigation;
- NO_X chemistry modelled based on simplified form of the Generic Reaction Set (GRS) chemistry scheme;
- Puff modelling option for simulation of instantaneous releases of pollutants;
- Predicts a range of short and long-term concentrations from 1-hour to annual average. Post-processing to calculate user-defined percentiles;
- ‘Fluctuations’ module for predicting ‘less than one hour’ average pollutant concentrations. The Fluctuations module accounts for the variation in concentration caused by the short time scale turbulence in the lower atmosphere (particularly for odour releases);
- Output in the form of a range of file types for analysis and plotting in spreadsheet and graphics software packages.

APPENDIX B - MM5 / CALPUFF

Numerical Weather Models

The output from a numerical weather model offers another potential source of representative meteorological data. An example of such a model is the Mesoscale Meteorological Model Version 5 (MM5), the output of which can be processed for use in Gaussian plume models such as AERMOD or ADMS 4 or in Lagrangian puff models such as CALMET/CALPUFF. These models have been highlighted in recent guidance[60] as offering some benefits over meteorological stations in certain circumstances:

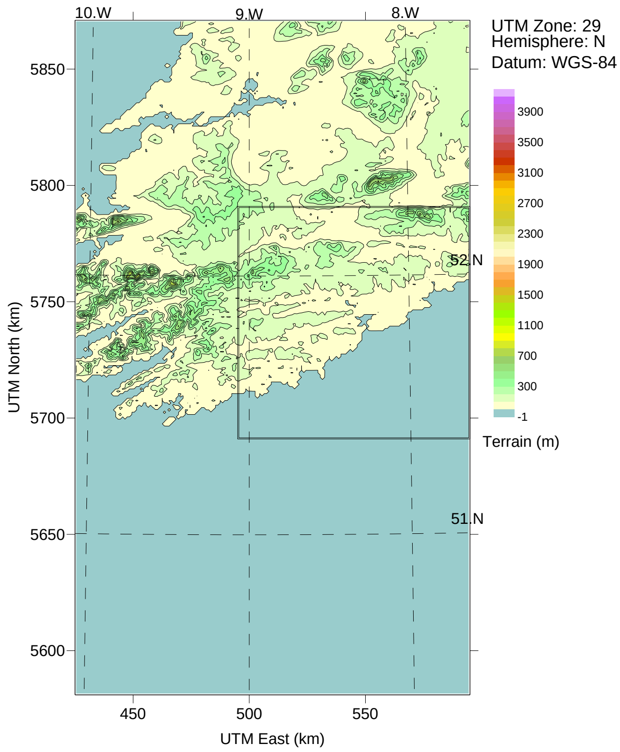
- Data can be provided for any location, which is useful if no suitable meteorological station is available;
- Data can be produced quickly using retrospective data as opposed to measurement of site-specific data which requires at least one year;
- Provides details of the space and time variability of the meteorology in three dimensions within the modelling domain (although Gaussian plume models cannot take full advantage of this spatial information).

The guidance does however caution that numerical models are still evolving and experience of using them for modelling in the near field (domains of less than 50km) is limited.

The use of MM5 data in the CALPUFF meteorological pre-processor CALMET has recently been the subject of some debate within the USEPA[61] with concerns raised regarding some technical aspects of the model (such as the convective boundary layer heights) and a perceived deficiency in model evaluations for CALMET/CALPUFF in the near field.

CALPUFF

CALPUFF is a multi-layer, multi-species non-steady-state Gaussian puff dispersion model that simulates the effects of time- and space-varying meteorological conditions on pollutant transport, transformation, and removal[13,22]. The modelling system is composed of the CALMET meteorological pre-processor, the CALPUFF dispersion model and the CALPOST post-processor for analysis of results (e.g. to determine long-term averages, prepare files for contour plots, etc.). The model can use 3-dimensional fields of meteorological data that are prepared by the CALMET meteorological pre-processor, and the model can account for spatial variability in meteorological conditions within the modelling domain. Pre-processors for land use and terrain are included with the model, the outputs of which are used as inputs to the CALMET pre-processor.



The CALPUFF system requires significant resources with regards to meteorological data, terrain data and land-use inputs but its value lies in its ability to model non-steady state scenarios that are outside the capabilities of both AERMOD and ADMS 4. Although model set-up requires extensive time, resources, expertise and effort, the necessary data is generally available to run the model.

The CALPUFF model is available to download as freeware from the Atmospheric Studies Group at the TRC Companies Inc. (TRC) website (http://www.src.com). The package includes all pre-processors and a graphical user interface.

Some features of the CALPUFF modelling system are:

- Lagrangian puff modelling system that can trace the trajectory of a plume over long time periods and distances (i.e. up to 300 kilometres);
- It is intended for use from tens of metres to hundreds of kilometres;
- Can model non-uniform meteorological conditions within the modelling domain;
- Can model the effect of complex terrain features and terrain downwash through the use of wind flow fields;
- Includes calculations on the effects of coastal fumigation;
- Can model complex chemical transformations including aerosol formation.

The key input parameters available for model usage are outlined below and can generally be found via links on the TRC website:

- Terrain data is freely available in the Shuttle Radar Topography Mission (SRTM) format that spans the globe from 60° north latitude to 56° south latitude with a horizontal grid spacing of 3 arc-seconds (approximately 90m);
- Land use data from the U.S. Geological Survey (USGS) and the European Commission's Joint Research Centre (JRC) based on a 1-km resolution Global Land Cover Characteristics (GLCC) database is freely available for Ireland as a gridded field of dominant land use categories and land-use weighted values of surface and vegetation properties for each grid cell;
- The CALMET file can include a range of data derived from surface meteorological stations, buoys, upper air stations and the output from mesoscale numerical weather modelling simulations. Penn State / NCAR Mesoscale Model (MM5) data is available for purchase covering all of Ireland (and Europe) for the Years 2006 and 2007 at a tile resolution of 12km x 12km. The data can be purchased in tiles covering an area of 120km x 120km and extends vertically to 25 vertical levels from 50m to 3500m. The hourly 3-D meteorological parameters included in the tiles are wind speed, wind direction, temperature, pressure, geo-potential height, vertical velocity, relative humidity, mixing ratios for water vapour, cloud water, rain, ice and snow. Hourly surface (2-D) parameters in the tiles include sea-level pressure, rainfall amount, snow cover, short wave and long wave radiation at the surface, air temperature at 2m, specific humidity at 2m, wind speed and wind direction at 10m and sea surface temperature;
- The Marine Institute records data at buoys M1 – M6 which are located off the coast of Ireland and which can be used in the CALMET meteorological file.

For many applications the much greater resources and complexity involved in running CALPUFF will not be warranted. However, under certain circumstances the model should be considered. These include:

- ***Significance changes in land use between the source and the location of maximum ground level concentration*** - AERMOD has land use variability only in terms of wind sectors centred at the meteorological station whilst ADMS 4 has the ability to produce 2-D variability for surface roughness only. CALPUFF has full 2-D variability for all surface parameters based on a grid.

- ***Horizontal wind variability*** - Gaussian plume models use a single station wind to characterise the entire modelling domain. Gaussian plume models cannot generally replicate the actual wind fields in complex meteorological zones, whilst CALPUFF, using a 3-D wind field gives a much more realistic result as shown in **Figure A1**.

- ***Regions of stagnation*** - Gaussian plume models typically fail at wind speeds less than 0.5 m/s. CALPUFF can specifically treat calm winds, although areas of stagnation (calm hours of 18 hours or greater) will be rare in Ireland.

- ***Cumulative impact assessments*** - Gaussian plume models have no memory of pollutants emitted during the previous hours. CALPUFF retains the previous hour's emissions within the domain and evaluates the impact from them. This may be important in a modelling domain where many installations are emitting similar pollutants during periods of low winds or calms.

- ***Coastal effects / fumigation*** - AERMOD does not consider fumigation although ADMS 4 does have a coastal module. CALPUFF has an overwater turbulence module and a Thermal Internal Boundary Layer (TIBL) algorithm to treat coastal fumigation.

The CALPUFF modelling system has USEPA regulatory status for use in long-range pollutant transport (between 50km and 300km)[13]. In relation to the status of CALPUFF in the near field (less than 50km) the USEPA has stated that:

> "*7.2.8 Complex Winds*
> *a. Inhomogeneous Local Winds. In many parts of the United States, the ground is neither flat nor is the ground cover (or land use) uniform. These geographical variations can generate local winds and circulations, and modify the prevailing ambient winds and circulations. Geographic effects are most apparent when the ambient winds are light or calm. In general these geographically induced wind circulation effects are named after the source location of the winds, e.g., lake and sea breezes, and mountain and valley winds. In very rugged hilly or mountainous terrain, along coastlines, or near large land use variations, the characterization of the winds is a balance of various forces, such that the assumptions of steady-state straight-line transport both in time and space are inappropriate. In the special cases described, the CALPUFF modelling system (described in Appendix A) may be applied on a case-by-case basis for air quality estimates in such complex non- steady-state meteorological conditions. The purpose of choosing a modelling system like CALPUFF is to fully treat the time and space variations of meteorology effects on transport and dispersion*. "[13]

The CALPUFF model undergoes regular updates (currently Version 6.262, dating from July 2008) and these are available on the website. However, not all updates have been approved by the USEPA. The USEPA website (http://www.epa.gov/scram001/dispersion_prefrec.htm) should be examined to obtain the latest information on the regulatory status of the model updates.

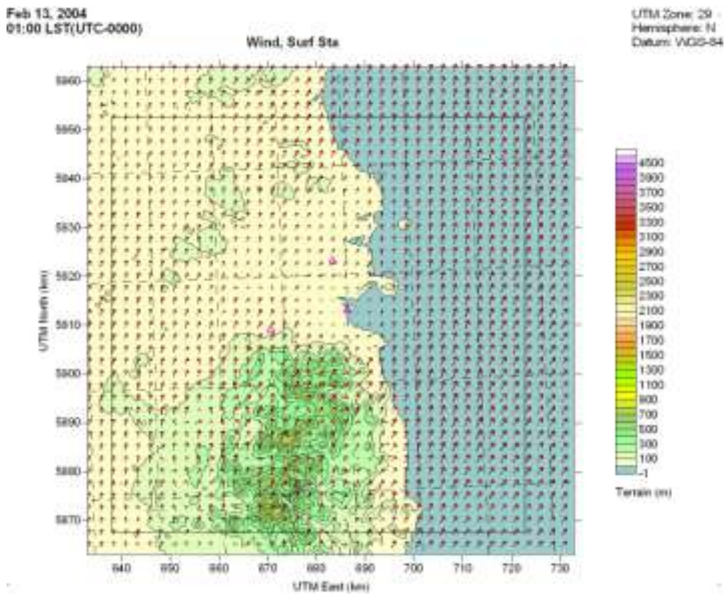


Figure A1 Example of a 3-D CALMET wind field using MM5, surface and buoy data for a single hour in 2004 in a region of 100km x 100km centred on Dublin.

APPENDIX C – EPA Guidelines on Selection of Dispersion Models

The aim of this document provides some guiding principles in relation to the selection of models for a given modelling scenario. This guideline relates primarily to modelling of emissions from industrial type activities as regulated by the EPA. The EPA does not specifically approve or support any specific air dispersion modelling package.

Dispersion models are a necessary and useful tool in assessing the impact of emissions to air from a given source. However, it is vital that the model outputs can be reliably used as an indicator of the likely worst case air quality impact due to the modelled input values.

In order for model results to be relied upon the model itself must be validated to demonstrate that the model can produce reliable results for a given modelling scenario (e.g. if modelling complex terrain conditions the model must have been validated for such conditions). The responsibility is on the modeller to ensure, and to provide evidence where required, that the model being used has been appropriately validated and peer reviewed, and to justify the model choice where required. The process of validation allows the performance of the model to be assessed and verified and allows confidence in the model results for scenarios under which validation of the model has occurred. It is recommended, particularly for more intricate modelling scenarios, that as part of modelling reports a section on 'model applicability' be included, comparing the modelled scenario (e.g. source parameters, terrain conditions, meteorological conditions, localised issues) to the range of conditions for which the model has been validated and peer reviewed.

In complicated modelling scenarios (particularly for complex terrain), or where the modelled scenario is on the margins of the conditions under which the model has been validated, the available 'headspace', i.e. the difference between the worst-case modelled impact (including background contributions) and the limit/guideline value should be substantial enough to allow confidence that any limit/guideline values will not be breached, taking into account the potentially poorer model performance in such situations.

The most common models encountered by the Agency are ISC, ADMS, AERMOD and associated screening models, and modelling assessments based on these models have been accepted by the Agency where the use of the model is appropriate to the conditions being modelled. The preference of the Agency in most situations would be for the newer generation Gaussian models, such as ADMS or AERMOD, to be used in preference to ISC, particularly for more complex modelling scenarios. Note that the USEPA Guidelines on Air Quality Models also recommends that AERMOD should be used instead of ISC.

Note on the use of screening models

Screening models are used as an initial tool to conservatively estimate the impact due to emissions from a given source, and eliminate or confirm a requirement for further detailed dispersion modelling. Such models typically use pre-defined meteorological parameters, negating the need for initial purchase of local meteorological data.

Screening assessments should employ worst-case inputs to ensure that the model outputs are conservative and provide a sound basis for deciding whether or not further detailed modelling is required. Where a screening assessment indicates that a predicted worst-case ground level concentration (including appropriate background pollutant concentrations) is significantly below applicable ambient air quality standards (or other appropriate guideline values in the absence of statutory limits) then further detailed dispersion modelling may not be required.

Where emissions from multiple sources are being assessed using a screening approach, the individual worst-case concentrations due to each individual source should be summed (and then added to the appropriate background concentration) for the purposes of estimating the overall impact.

Useful References:

Good Practice Guide for Atmospheric Dispersion Modelling, New Zealand Env. Ministry 2004

UK Atmospheric Dispersion Modelling Liaison Committee, 2004. Guidelines for the Preparation of Dispersion Modelling Assessments for Compliance with Regulatory Requirements – an Update to the 1995 Royal Meteorological Society Guidance.

USEPA, 2005. Revision to the Guideline on Air Quality Models: Adoption of a Preferred General Purpose (Flat and Complex Terrain) Dispersion Model and Other Revisions; Final Rule. Federal Register 40 CFR Part 51.

APPENDIX D – Met Eireann Meteorological Stations

Station Number	Name	Altitude (m)	Latitude	Longitude	Opening Year	Anemometer Threshold Wind Speed (m/s) Note 1	Manual Cloud Cover Measurements
305	Valentia Observatory	11	51.94	-10.244	1866	< 0.5 m/s	Yes
375	Oak Park	63	52.861	-6.915	2003	< 0.5 m/s	No
475	Johnstown Castle	53	52.292	-6.5	2003	< 0.5 m/s	No
518	Shannon Airport	6	52.69	-8.918	1937	< 0.5 m/s	Yes
532	Dublin Airport	71	53.428	-6.241	1939	< 0.5 m/s	Yes
545	Malin Head	22	55.372	-7.339	1957	1 m/s	Yes
675	Ballyhaise	79	54.051	-7.31	2003	< 0.5 m/s	No
875	Mullingar	100	53.537	-7.362	2002	< 0.5 m/s	No
1004	Roches Point	43	51.793	-8.244	1877	< 0.5 m/s	No
1034	Belmullet	11	54.228	-10.007	1956	1 m/s	Yes
2437	Clones Note 2	89	54.183	-7.233	1950	1 m/s	-
2615	Rosslare Note 2	26	52.25	-6.335	1956	1 m/s	-
2727	Claremorris	71	53.711	-8.991	1943	< 0.5 m/s	No
3613	Kilkenny Note 2	66	52.665	-7.269	1957	< 0.5 m/s	-
3723	Casement	94	53.306	-6.439	1944	< 0.5 m/s	No
3904	Cork Airport	154	51.847	-8.486	1961	< 0.5 m/s	Yes
4919	Birr Note 2	73	53.09	-7.89	1954	< 0.5 m/s	-
4935	Knock Airport	203	53.906	-8.817	1986	< 0.5 m/s	Yes

Note 1 Dines Anemometers are in use in Malin Head and Belmullet and formerly in Clones and Rosslare with a threshold of 2-3 knots (1-1.5 m/s).

Note 2 Closed in 2008.

Table A1 Meteorological Stations Operated By Met Eireann

APPENDIX E – UK DEFRA Guidance In Relation To Background Concentrations

Estimating Annual Mean Background Concentration Based On Shorter-Term Survey

Guidance is available from the UK DEFRA[(50)] in relation to estimating the long-term (annual) averages from a shorter-term monitoring survey (a minimum of 3 months is recommended in the guidance). The approach is based on the fact that patterns in pollutant concentrations usually affect a wide region. Thus a short-term peak at one location is usually replicated at similar sites up to 80km away. The adjustment procedure is outlined below for a three-month monitoring period (Jan – Mar) at site A:

- 2 - 4 long-term monitoring sites should be used to obtain annual means (from available EPA / Local Authority urban background or background sites[(48)] within 80km if possible);
- The 3-month average (Jan-Mar) at these 2-4 monitoring sites is then calculated and compared to the 3-month average (Jan-Mar) at site A;
- The ratio of the mean during this period (Jan-Mar) to the annual mean is then determined for the 2-4 monitoring sites;
- The average ratio derived from the 2-4 monitoring sites is then applied to Site A to obtain an estimate of the annual average.

Combining Short-Term Process Contribution With Background Concentration

In relation to combining short-term peak concentrations with background concentrations, guidance from the UK DEFRA[(50)] advises that for NO_2, SO_2 and PM_{10} an estimate of the maximum combined pollutant concentration can be obtained as shown below:

NO_2 - The 99.8th%ile of total NO_2 is equal to the minimum of either A or B below:

a) 99.8th%ile hourly background total oxidant (O_3 & NO_2) + 0.05 x (99.8th%ile process contribution NO_X)

b) The maximum of either:

- 99.8th%ile process contribution NO_X + 2 x (annual mean background NO_2); or

- 99.8th%ile hourly background NO_2 + 2 x (annual mean process contribution NO_X).

SO_2 - The 99.7th%ile of total 1-hour SO_2 is equal to the maximum of either A or B below:

a) 99.7th%ile hourly background SO_2 + (2 x annual mean process contribution SO_2)

b) 99.7th%ile hourly process contribution SO_2 + (2 x annual mean background contribution SO_2)

SO_2 - The 99.2th%ile of total 24-hour SO_2 is equal to the maximum of either A or B below:

a) 99.2th%ile of 24-hour mean background SO_2 + (2 x annual mean process contribution SO_2)

b) 99.2th%ile 24-hour mean process contribution SO_2 + (2 x annual mean background contribution SO_2).

PM_{10} - The 90.4th%ile of total 24-hour mean PM_{10} is equal to the maximum of either A or B below:

a) 90.4th%ile of 24-hour mean background PM_{10} + annual mean process contribution PM_{10}

b) 90.4th%ile 24-hour mean process contribution PM_{10} + annual mean background PM_{10}

The guidance suggests that the results should be conservative using this approach. Where an exceedance is approached (75% of the ambient limit values) a more detailed investigation using hour by hour process concentrations may be necessary.

APPENDIX F – Cumulative Impact Assessments

Where an existing nearby major air emission point source has been identified near the installation under consideration, a methodology is required to determine whether this nearby source needs to be included in the air dispersion modelling assessment and if so which pollutants should be included. The need for such an assessment is however expected to be limited and consultation with the EPA should be undertaken prior to carrying out a detailed cumulative assessment. Once this review has been undertaken and the need for the cumulative assessment established, a further methodology is required to determine whether the cumulative impact arising is significant.

To help answer these questions, a USEPA methodology is available and may be adapted for use in Ireland. The USEPA methodology is used in the US to assess air emissions from industrial installations, which have the potential to emit more than 250 tonnes/annum of any regulated pollutant (or 100 tonnes/annum for 28 specific industries including cement manufacturers, power stations and municipal waste incinerators)[(62)].

The approach, termed the Prevention of Significant Deterioration (PSD) Increment approach is based on allowing a specific incremental release (termed PSD increment) from each installation. The PSD increment can be viewed as the maximum relative increase in concentration (as a percentage of the ambient air quality standard) that is allowed to occur for each pollutant from each installation. However, no exceedance of the ambient air quality limit values is allowed even if not all of the PSD increment is consumed.

The USEPA has defined "significance" in the current context as an impact leading to a 1μg/m^3 annual increase in the annual average concentration of the applicable criteria pollutant (PM_{10}, NO_2, and SO_2)[(62)]. However, no significant ambient impact levels have been established for non-criteria pollutants (defined as all pollutants except PM_{10}, NO_2, SO_2, CO and lead). The USEPA does not require a full cumulative assessment for a particular pollutant when emissions of that pollutant from a proposed source would not increase ambient levels by more than the significant ambient impact level. Based on broadly similar principles, "significance", in an Irish context, for any pollutant may be defined as an impact leading to a 5% increase in the applicable ambient air quality standard (AQS).

The "impact area" for the cumulative assessment is defined by the USEPA as a circular area with a radius extending from the source to the most distant point where dispersion modelling predicts a "significant" ambient impact (i.e. >5% of an AQS) will occur irrespective of pockets of insignificant impact occurring within it. Within this impact area, all nearby sources should be modelled, where "nearby" is defined as any point source expected to cause a significant concentration gradient in the vicinity of the proposed new installation.

The PSD has three classifications of land use. Class I refers to national parks, Class III refers to heavily industrialized areas and Class II to everywhere except Class I and Class III areas. However, for simplicity it is suggested that an increment of 25% of the AQS (as outlined in **Table A2**) should be used for assessing impacts at all locations in Ireland. Again, for ease of use, it is suggested that a single limit of 100 tonnes/annum of any regulated pollutant from the existing installation be used as the threshold level.

Pollutant	Averaging Period	Significance Level µg/m³	PSD Increment (as a % of EU Directives)	PSD Increment as applied to EU Standards (µg/m³) / Averaging Periods
PM_{10}	Annual 24-Hour	2 2.5	25%	Annual - 10 24-Hour – 12.5
$PM_{2.5}$ (1)	Annual	1.25	25%	Annual - 6.25
SO_2	24-Hour 1-Hr	6.25 17.5	25%	24-Hour – 31.3 1-Hour – 87.5
NO_2	Annual 1-Hr	2.0 10	25%	Annual - 10 1-Hour - 50

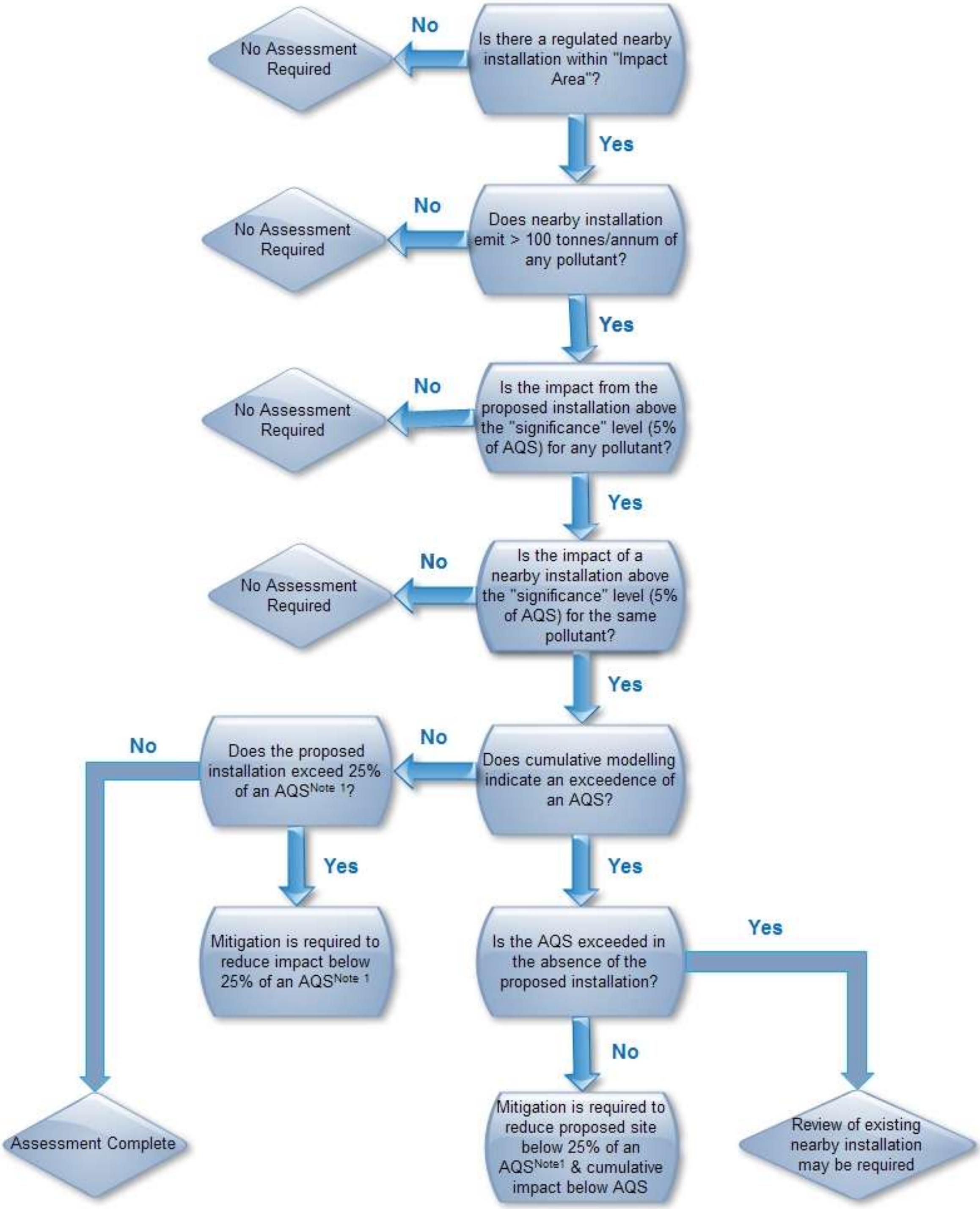
(1) PSD Increment not designated - based on the PSD increment for PM_{10}.

Table A2 PSD Increments As Applied To EU Directives

In order to determine compliance, the predicted ground level concentration (based on the full cumulative analysis and existing background data) at each model receptor is compared to the applicable ambient air quality limit value or PSD increment in the region of overlap between the impact area of the proposed installation and the existing installation. If the predicted pollutant concentration increase over the baseline concentration is below the applicable increment (i.e. 25% of the AQS), and the predicted total ground level concentrations are below the ambient air quality standards, then the applicant has successfully demonstrated compliance.

When an air quality standard or PSD increment is predicted to be exceeded at one or more receptors in the impact area, it should be determined whether the net emissions increase from the proposed installation will result in a significant ambient impact at the point of each exceedance, and at the time the exceedance is predicted to occur(62). A flowchart of the cumulative impact assessment is outlined in **Figure A2**.

When carrying out a detailed cumulative assessment, model input information relating to a nearby industrial installation may be available from the EPA website or by viewing hardcopies of the licence application. Where data is deficient, conservative estimates should be made in relation to the nearby installation.



Note 1: Applies only in the region of overlap between the impact area of the proposed installation and the existing installation.

Figure A2 Flowchart for undertaking a cumulative impact assessment of a nearby industrial installation (based on the USEPA PSD approach[62]).

APPENDIX G – Deposition Modelling

Modelling of wet and dry deposition from both gaseous and particulate pollutants can be undertaken using both ADMS and AERMOD. Wet deposition of both particulate and gaseous pollutants can occur mainly as a result of precipitation. Dry deposition is also possible for both particulate and gaseous pollutants by means of various processes including gravitational settling, Brownian motion and inertial impaction(52). Depletion of the plume will also occur as a result of both wet and dry deposition as a function of downwind distance.

Gaseous Deposition

Wet Gaseous Deposition

Wet gaseous deposition physically washes out the gaseous pollutants from the atmosphere. The wet gaseous deposition flux depends on the precipitation rate (in mm/hr), the concentration of the pollutant in the liquid phase and the molecular weight of the pollutant.

ADMS 4 uses a washout coefficient which can be modelled using a constant value which is independent of the precipitation rate (and thus lead to wet deposition in the absence of precipitation). Alternatively, the washout coefficient can be modelled as a function of pollutant species and rainfall rate only with defaults suggested in the absence of pollutant specific values(21,63). ADMS 4 also has specific options for modelling dry deposition of HCl, SO_2 and CO_2. The first method specific to SO_2 and CO_2 is based on a washout coefficient that is pH-limited. The scheme calculates the aqueous concentration of either SO_2 or CO_2 in the rainfall that has passes through the plume without considering the limiting effect of pH. This concentration is then compared to the maximum allowable aqueous concentration if the pH was taken into account. This second concentration then sets an upper limit to the aqueous concentration which can occur(63).

The second method in ADMS 4 is termed the "falling drop" method which is specific to SO_2 and HCl from point sources. In this method, account is taken of the reversibility of the some gaseous to aqueous conversions (such as SO_2) when the plume centreline enters a region of relatively clean air. Thus, the ground level aqueous concentration of SO_2 may be less than the maximum concentration which occurs near the plume centreline(63). The method is implemented in ADMS based on the kinetic and thermodynamic processes of SO_2 and HCl as a coupled system and the user-entered pH of the rain entering the top of the plume. The additional information required in order to run this module is the initial pH of the droplets entering the plume(63).

The AERMOD deposition algorithm(52) based on a washout coefficient assumes that the wet gaseous deposition flux is the same for snow as for rain.

For both models, precipitation data (in mm/hr), which is not routinely included in the meteorological files, will be required on an hourly basis and is available from Met Eireann.

Dry Gaseous Deposition

Dry deposition in ADMS 4 is modelled using a deposition velocity based on a diffusive parameter and a gravitational settling parameter (which is set to zero for gases). The removal of material at the surface results in a modified vertical distribution due to depletion of the plume from the surface only. Deposition velocities are assumed to be constant throughout the modelling domain with the exception of complex terrain (in circumstance where the deposition velocity is specified as unknown). In complex terrain, the model calculates the deposition velocity based on gas type (reactive, non-reactive, inert) and the local value of the friction velocity. For gaseous pollutants, the limiting resistance terms to deposition are sub-layer resistance and surface resistance(64).

In ADMS, the deposition velocity can be input directly if known. If unknown, the deposition velocity can be estimated based the nature of the gas (reactive (such as SO_2, NO_X), non-reactive (CO_2), inert (noble gases))(21,64).

The dry gaseous deposition formulation in AERMOD is based on three resistance terms; aerodynamic resistance, quasi-laminar resistance to bulk transfer and a bulk surface resistance term[(52)]. The four physiochemical parameters required to calculate these resistance terms are:

- D_a (diffusivity of modelled gas in air (cm/s));
- D_w (diffusivity of modelled gas in water (cm/s));
- Henry's Law constant for modelled gas (Pa-m^3/mol), and;
- r_{cl} (leaf cuticular resistance (s/m)).

Default values are given in Appendix B of the technical report[(52)] for a range of pollutants. Land use characterisation is also required out to 3km from the installation being modelled.

Particulate Deposition

Wet Particulate Deposition

Wet particulate deposition physically washes out particulates from the atmosphere. The wet deposition flux depends on the fraction of the time precipitation occurs and the fraction of material removed by precipitation (per unit of time) by particle size. ADMS 4 uses a washout coefficient which can be modelled in the default option dependent on the pollutant type and the precipitation rate[(21)]. The AERMOD model formulation is based on a particle washout coefficient, which is based on the collision efficiency and the mean diameter of raindrops. It is also assumed that the wet deposition flux is the same for snow as for rain[(52)].

Dry Particulate Deposition

ADMS 4 models dry particulate deposition based on both a gravitational settling velocity and by diffusion. For particulate pollutants, surface resistance is usually negligible[(64)] whilst a minimum deposition velocity usually occurs between 0.1 – 1 μm where neither sub-layer transport nor gravitational settling is particularly effective. ADMS 4 requires the specification of deposition and terminal velocities, where known, in addition to information on the mass fraction. Where the deposition or terminal velocities are not known particle diameter, particle density and mass fraction distributions are required[(21)]. Up to ten particle diameter and particle density combinations can be entered into the model.

In AERMOD[(52)], dry particulate deposition is based on a resistance scheme in which the deposition velocity is based on the predominant particle size distribution via two methods:

- **Method 1** is used when a significant fraction (> 10%) of the total particulate mass has a diameter greater than 10 microns and the particle size distribution is reasonably well known. The method is based on the gravitational settling velocity and two resistance terms; aerodynamic resistance and quasi-laminar resistance to bulk transfer.
- **Method 2** is used when the particle size distribution is not well known and when a small fraction (less than 10% of the mass) consists of particles with a diameter of 10 microns or larger. The deposition velocity for method 2 is given as the weighted average of the deposition velocity for the coarse mode and fine mode.

When modelling particulates in AERMOD, the option exists to select either the surface area weighting or the mass weighting depending on pollutant type. The surface weighting reflects the mode of formation where volatiles condense on the surface of particulates and would be appropriate for Polycyclic Organic Compounds (POCs) and mercury. In these cases, the apportionment of emissions by particle size becomes a function of the surface area of the particle which is available for chemical adsorption[(65)]. For heavy metals (except mercury), particle size distributed by mass weighting is appropriate.

APPENDIX H – NO_2/NO_X Chemistry

During combustion processes, a mixture of both nitric oxide and nitrogen dioxide is released and once released a series of complex chemical reactions takes place during which a portion of the nitrogen oxide is converted to nitrogen dioxide. The volume fraction of NO_2 in the exhaust gas is typically assumed to be between 5 – 10%(66).

In terms of atmospheric chemistry, NO reacts with ozone (O_3) to form NO_2 and O_2:

(1) $NO + O_3 \rightarrow NO_2 + O_2$

Additional reactions can occur to reform NO and O_3 from the reaction of NO_2 with sunlight:

(2) $NO_2 + h\nu \rightarrow NO + O$

(3) $O + O_2 \rightarrow O_3$

Due to the nature of equations (1) – (3) a quasi-equilibrium ratio of NO_2/NO_X will eventually be established. Empirical evidence suggests that this ratio will be of the order of 0.75 – 0.90(66).

The USEPA has suggested several approaches to determining the fraction of NO_2 in the ambient environment(13). The approaches (termed Tier 1 – Tier 3) range from:

- total conversion (100% NO_2) (Tier 1),
- a default annual NO_2/NO_X ratio of 0.75 (Tier 2),
- a detailed screening method such as the ozone limiting method (OLM) or the Ambient Ratio Method (ARM) (Tier 3).

It should be borne in mind that the USA has solely an annual average air quality standard for NO_2 and thus the approaches described by the USEPA are focused on this averaging period only.

The OLM assumes that the amount of NO converted to NO_2 via reaction (1) is proportional to the ambient ozone concentration. Where the ozone concentration is greater than NO, full conversion to NO_2 is assumed. The OLM also ignores reactions (2) and (3) and assumes that initially 10% of the plume is NO_2. In general, the OLM would be viewed as very conservative and no longer considered suitable for use.

The ARM uses empirically derived NO_2/NO_X ratios from representative ambient monitoring stations. The guidance suggests that the station should be at a location where the NO_2/NO_X ratio is in quasi-equilibrium. Empirical evidence suggest that quasi-equilibrium conditions may not be established until many kilometres downwind(66). If monitoring is undertaken at the point of maximum ambient concentration (which may be of most interest), the ratio derived is only valid for receptors located at the same distance from the source as the monitoring station.

In the UK, guidance(23) is given in regards to both short-term and long-term conversion factors. The recommended UK conversion factors are:

- short-term (1-hour) average: assume a conversion factor for NO_2/NO_X of 0.50;
- annual mean: assume a conversion factor for NO_2/NO_X of 1.0 (total conversion).

AERMOD treats the NO_2/NO_X conversion via three options:

- no conversion – the results are expressed in terms of NO_X (a default conversion factor can be applied thereafter);

- the OLM method;
- the Plume Volume Molar Ratio Method (PVMRM)[67, 68].

The PVMRM, which is currently a non-regulatory option in AERMOD, uses the same chemistry as OLM but additionally uses both plume size and O_3 concentration to derive the amount of O_3 available for the reaction between NO and O_3. In contrast, the OLM ignores plume size. NO_X moles are determined by emission rate and travel time through the plume segment. The number of O_3 moles is determined by the size of the plume segment and the measured background ambient O_3 concentration. For a given NO_X emission rate and ambient ozone concentration, the NO_2/NO_X conversion ratio is primarily controlled by the volume of the plume in contrast to the OLM which is primarily controlled by the ground-level NO_X concentration[69]. The method has been shown to give better agreement with monitoring data than either the OLM or the ARM as a function of downwind distance from the source.

The current default options in AERMOD-PVMRM are:

- for background ozone, a single representative value or hour-by-hour data from a representative monitoring station can be used;
- NO_2/NO_X equilibrium ratio = 0.90;
- NO_2/NO_X in-stack ratio = 0.10.

ADMS 4 uses the Generic Reaction Set (GRS) (which is a semi-empirical photochemical model) of equations and which are based on the reactions and rates of equations (1) – (3).

Reaction (1) is temperature dependent whilst reaction (2) is dependent on the solar radiation. Thus, during summer a photo-stationary equilibrium is reached with a few minutes whilst in winter the reaction will proceed more slowly. As reaction rates for (2) – (3) are dependent on the amount of solar radiation, either solar radiation or cloud cover information is required.

The chemical reactions are modelled over a time period which is dependent on the age of the pollutants NO and NO_2. Mean ages of the emitted NO and NO_2 are calculated with the mean age taken as the minimum of the two mean ages[70]. The main assumption in the scheme is that background pollutants are mixed instantaneously into the plume. This assumption has been found to be only marginally conservative except close to the source at plume height[70].

In relation to background concentrations, the model cautions that this should not include the contribution from the source being modelled. The suggestion is that in rural locations rural background values should be used and in industrial areas in urban locations only urban background values should be used. A default of 10% of the emitted plume as NO_2 is used[21].

APPENDIX I – Odour Modelling

This document does not endeavour to provide definitive guidance on odour modelling but rather gives an outline of some of the major considerations which may need to be taken into account.

The perception of odour is complex and a number of properties of odour need to be considered when modelling is to be undertaken:

- **intensity of the odour** - odour intensity is a measure of the strength of the odour sensation and is related to the odour concentration. However, this relationship is logarithmic in nature (Stevens' Law). Thus, when considering abatement options, it should be noted that if the concentration of the odour decreases tenfold, the perceived intensity will decrease by a much smaller amount[(71)];
- **odour character** - the character of an odour distinguishes it from another odour of equal intensity on the basis of odour descriptor terms (e.g. putrid, fishy, fruity etc.);
- **hedonic tone** - the hedonic tone of an odour relates to its pleasantness or unpleasantness;
- **frequency of occurrence of the odour** - several time-dependent characteristics are of importance including the total duration of impact, frequency of impact and the time of day/week/year.

Odour Emission Rates

There are two general approaches to assessing odour emission rates from industrial installations. One approach is to assess the emissions from the installation in terms of Odour Units (OU or OU_E/m^3). A second approach is to use a chemical marker which it is assumed will correlate with the odour detected at the boundary or the nearest residential receptor.

For existing installations, direct measurement of odour using olfactometry is recommended. The measurement from each stack should be conducted in duplicate, and for the most significant sources in triplicate, in order to reduce uncertainty and to enable the identification of outliers. Sampling in triplicate (compared to duplicate) reduces the uncertainty at the 95% confidence interval around a mean of 1000 OU_E /m^3 from a range of 480 - 2090 OU_E /m^3 to 620 -1600 OU_E /m^3[(56)]. Sampling and analysis for a specific chemical can only be undertaken adequately where the release is a single compound although even in this case finding accurate odour detection thresholds can be problematic. Where more than one compound is present, olfactometry is the preferred approach due to the synergistic and non-linear effects of multiple odorous compounds.

For proposed installations or expansions of existing operations, the modeller should ensure that the emission rates used are fully justified in the report. Sources of data may include libraries of data from similar existing installations in Ireland (preferably), data from similar existing installations in other jurisdictions or available emission factors (such as USEPA AP-42 database[(72)]).

Relevant Odour Standards

The exposure of the population to a particular odour consists of two factors; the concentration and the length of time that the population may perceive the odour. By definition, 1 OU_E/m^3 is the detection threshold of 50% of a qualified panel of observers working in an odour-free laboratory using odour-free air as the zero reference.

Currently there is no general statutory odour standard in Ireland relating to industrial installations. The EPA[(53)] has issued guidance specific to intensive agriculture which has outlined the following standards:

- Target value for new pig-production units of 1.5 OU_E/m^3 as a 98^{th}%ile of one hour averaging periods,

- Limit value for new pig-production units of 3.0 OU_E/m^3 as a 98^{th}%ile of one hour averaging periods,
- Limit value for existing pig-production units of 6.0 OU_E/m^3 as a 98^{th}%ile of one hour averaging periods.

Guidance from the UK recommends that odour standards should vary from 1.5 – 6.0 OU_E/m^3 as a 98^{th}%ile of one hour averaging periods at the worst-case sensitive receptor based on the offensiveness of the odour and with adjustments for local factors such as population density[54,55]. A summary of the indicative criterion is given below in **Table A3**:

Industrial Sectors	Relative Offensiveness of Odour	Indicative Criterion
Rendering Fish Processing Oil Refining Creamery WWTP Fat & Grease Processing	High	1.5 OU_E/m^3 as a 98^{th}%ile of hourly averages at the worst-case sensitive receptor
Intensive Livestock Rearing Food Processing (Fat Frying) Paint-spraying Operations Asphalt Manufacture	Medium	3.0 OU_E/m^3 as a 98^{th}%ile of hourly averages at the worst-case sensitive receptor
Brewery Coffee Roasting Bakery Chocolate Manufacturing Fragrance & Flavouring	Low	6.0 OU_E/m^3 as a 98^{th}%ile of hourly averages at the worst-case sensitive receptor

Table A3 Indicative Odour Standards Based On Offensiveness Of Odour

A second approach recommended by the New Zealand Ministry for the Environment[57] is based on sensitivity of the receiving environment rather than the offensiveness of the odour. A summary of the recommended guideline values is given below in **Table A4**:

Sensitivity of the Receiving Environment	Examples of Land-Use Type	Concentration	Percentile (based on 1-hour means)
High (worst-case impacts under unstable / semi-unstable conditions)	High / Low Density Residential Recreational / Open Spaces Retail /Education / Business/ Cultural	1.0 OU_E/m^3	0.1% and 0.5%
High (worst-case impacts under neutral to stable conditions)		2.0 OU_E/m^3	0.1% and 0.5%
Moderate (all conditions)	Light Industry	5.0 OU_E/m^3	0.1% and 0.5%
Low (all conditions)	Heavy Industry Public Road	5 - 10 OU_E/m^3	0.5%

Table A4 Recommended Odour Modelling Guideline Values

The guidance states that the "baseline" percentile should be the 0.5% although the 0.1% maybe used to assist in the evaluation of model results. The guidance given in this document is that the approaches adopted in the UK and New Zealand are reasonable and can be used for assessing the release of odorous compounds from industrial installations in Ireland.

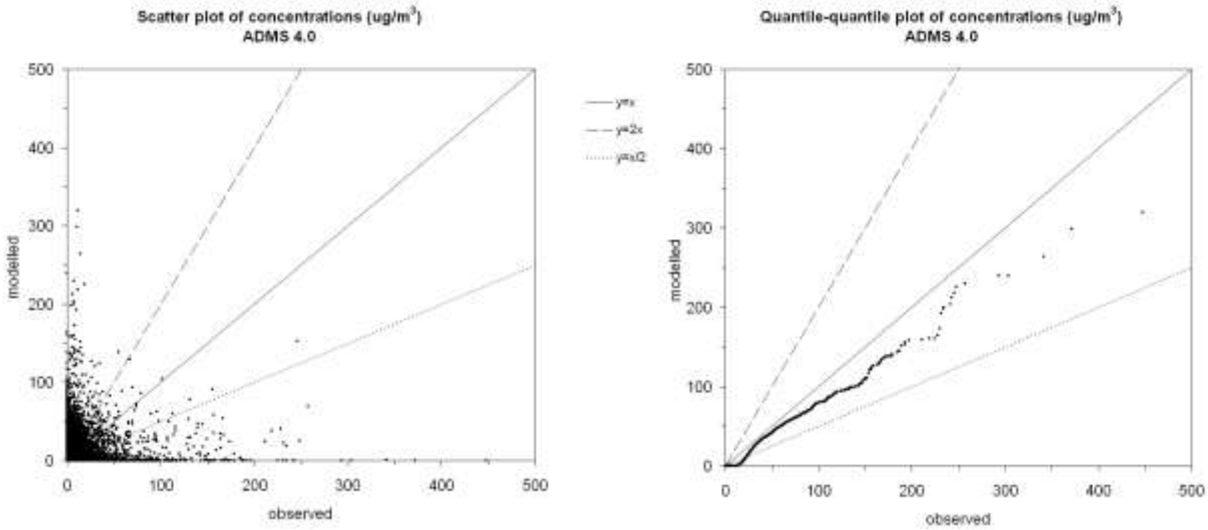
Odour Modelling

Odour modelling can be undertaken using either ADMS 4 or AERMOD using the same principals as are used when modelling the release of any other pollutant. Both models have the capability of accepting emission rates in terms of OU_E/sec and producing ground level concentrations in terms of OU_E/m^3. The same principals in relation to meteorology, terrain and building downwash will also apply to odour modelling. When modelling odour, it should be understood that measurement of ambient background levels of odour and incorporation of these into the modelling results is not a valid approach[54,55].

APPENDIX J – Model Validation

Both AERMOD and ADMS 4 have undergone extensive validation studies where modelled predictions have been compared to actual measurements in order to determine the accuracy of the model. Due to the uncertainties in wind direction, model comparison studies are not compared paired in space and time (see **Figure A3**). The issue has been addressed in an AERMOD Evaluation Report[73]:

> *"Operational performance of models for predicting compliance with air quality regulations, especially those involving a peak or near peak value at some unspecified time and location can be assessed with quantile-quantile (Q-Q) plots. Q-Q plots, are created by sorting by rank the predicted and the observed concentrations from a set of predictions initially paired in time and space. The sorted list of predicted concentrations are then plotted by rank against the observed concentrations also sorted by rank. These concentration pairs are no longer paired in time or location. However, the plot is useful for answering the question, "Over a period of time and over a variety of locations, does the distribution of the model predictions match those of observations?" Scatterplots, which use data paired in time (and / or space), provide a more strict test, answering the question: "At a given time and place, does the magnitude of the model prediction match the observation?" It is the experience of model developers that wind direction uncertainties can and do cause disappointing scatterplot results from what are otherwise well-performing dispersion models. Therefore, the Q-Q plot instead of the scatterplot is a more pragmatic procedure for demonstrating model performance of applied models.''*



Scatter plots and quantile-quantile plots of ADMS results against observed concentrations (ug/m³).

Figure A3 Comparison between the same data which is paired in time and space (scatter plot) and secondly unpaired in time and space (Q-Q Plot) (*taken with permission from CERC (2007) ADMS 4 Complex Terrain Validation Lovett Power Plant)* [74]

The purpose of the validation studies undertaken by ADMS and AERMOD[73,74] was to be confident that these models had been tested in a variety of types of environments for which they will be used. The types of studies ranged from non-buoyancy releases in flat terrain, buoyant releases in flat terrain, buoyant releases in complex terrain and buoyant releases in mountainous terrain. The studies included the Tracy Power Plant (Nevada) study, located in a rural river valley surrounded by mountainous terrain with emissions taking place from a 91m moderately buoyant stack. The Martins Creek study is characterised by complex terrain rising above the stacks (stacks varying from 122 – 183m). Monitoring was carried out on a

mountain 2.5 – 8 km from the installation. The Lovett power plant study again is a buoyant release study carried out in complex terrain (rising to nearly 200 m above stack height).

The overall evaluation for AERMOD indicated that:

- 1.03 is the overall predicted-to-observed ratio for short-term averages (with a range among sites from 0.76 to 1.35) (and 0.97 for cases involving PRIME),

- 0.73 is the overall predicted-to-observed ratio for annual averages (with a range among sites from 0.30 to 1.64).

The predicted-to-observed ratio did not vary substantially between simple and complex terrain sites. The report compared these results to the previous regulatory model, ISCST3, for which a large change in the average ratio was evident (0.96 for simple terrain and 6.4 for complex terrain)[(73)].

Similarly, in relation to ADMS agreement with observation is within a factor of two and much better than this in some cases[(74)].

A study by Hanna et al (2001)[(75)] carried out an independent inter-comparison exercise between ADMS, AERMOD and ISCST3. This study concluded that:

> "*Analysis of the model performance measures suggest that ISC3 typically over-predicts, has a scatter of about a factor of three, and has about 33% of its predictions within a factor of two of observations. The ADMS performance is slightly better than the AERMOD performance and both perform better than ISC3. On average, ADMS under-predicts by about 20% and AERMOD under-predicts by about 40%, and both have a scatter of about a factor of two. ADMS and AERMOD have about 53% and 46% of their predictions within a factor of two of observations, respectively. Considering only the highest predicted and observed concentrations, ISC3 over-predicts by a factor of seven, on average, while ADMS and AERMOD under-predict by about 20%, on average.*"

A second study by Hall et al (2000)[(76)] for the UK Environment Agency found that:

> *"The ADMS and AERMOD 'advanced' models investigated here are likely to be the main contenders for such work at present and we can find no reason from the present study to specifically exclude either of them from such work. There remains a usefulness for the older, Pasquill/Gifford type of model (mainly the ISC and R91 models in the UK) for rapid screening studies and other work. They are fast, easily understood and retain an historical link with earlier regulatory studies. However, the 'advanced' models have in principle a better capacity for dealing with more complex meteorological situations and should be the preferred models for regulatory studies, particularly in complex or contentious situations."*

A recent comparison of the two models, ADMS and AERMOD, was presented at the 11th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes by Brooke et al (2007)[(77)]:

> "*Most results from both ADMS 3.3 and AERMOD (04300) agreed with measured 1 hour SO_2 concentration statistics to within a factor of two, indicating that both models are fit-for-purpose. Further studies would be required to examine the reasons for the differences between modelled and measured results in more detail, and to understand the differences between the output from the AERMOD and ADMS meteorological pre-processors*."

APPENDIX K – Ambient Air Quality Standards / Guidelines

The air quality standards currently applicable in Ireland are the EU ambient standards which are outlined in **Tables A5 – A6**.

Pollutant	Regulation [Note 1]	Limit Type	Margin of Tolerance	Value
Nitrogen Dioxide	2008/50/EC	Hourly limit for protection of human health - not to be exceeded more than 18 times/year	40% until 2003 reducing linearly to 0% by 2010	200 µg/m^3 NO_2
		Annual limit for protection of human health	40% until 2003 reducing linearly to 0% by 2010	40 µg/m^3 NO_2
		Annual limit for protection of vegetation	None	30 µg/m^3 NO + NO_2
Lead	2008/50/EC	Annual limit for protection of human health	100%	0.5 µg/m^3
Sulphur dioxide	2008/50/EC	Hourly limit for protection of human health - not to be exceeded more than 24 times/year	150 µg/m^3	350 µg/m^3
		Daily limit for protection of human health - not to be exceeded more than 3 times/year	None	125 µg/m^3
		Annual & Winter limit for the protection of ecosystems	None	20 µg/m^3
Particulate Matter (as PM_{10})	2008/50/EC	24-hour limit for protection of human health - not to be exceeded more than 35 times/year	50%	50 µg/m^3 PM_{10}
		Annual limit for protection of human health	20%	40 µg/m^3 PM_{10}
$PM_{2.5}$ (Stage 1)	2008/50/EC	Annual limit for protection of human health	20% from June 2008. Decreasing linearly to 0% by 2015	25 µg/m^3 $PM_{2.5}$
$PM_{2.5}$ (Stage 2)		Annual limit for protection of human health	None	20 µg/m^3 $PM_{2.5}$
Benzene	2008/50/EC	Annual limit for protection of human health	100% until 2006 reducing linearly to 0% by 2010	5 µg/m^3
Carbon Monoxide	2008/50/EC	8-hour limit (on a rolling basis) for protection of human health	60%	10 mg/m^3 (8.6 ppm)

Note 1 EU 2008/50/EC – Clean Air For Europe (CAFÉ) Directive replaces the previous Air Framework Directive (1996/30/EC) and daughter directives 1999/30/EC and 2000/69/EC

Table A5 European Union Ambient Air Quality Standard (Based on Directive 2008/50/EC)

Pollutant	Regulation	Target Type	Value[Note 1]
Arsenic	2004/107/EC	Annual target value for protection of human health	6 ng/m^3
Cadmium	2004/107/EC	Annual target value for protection of human health	5 ng/m^3
Nickel	2004/107/EC	Annual target value for protection of human health	20 ng/m^3
Benzo(a)pyrene	2004/107/EC	Annual target value for protection of human health	1 ng/m^3

Note 1 Based on the total content in the PM_{10} fraction averaged over a calendar year.

Table A6 Council Directive 2004/107/EC

Where no EU air quality standard exists, relevant statutory standards from other EU countries such as the UK, Germany or Denmark should be used. The most stringent European guideline / limit value from the sources outlined below should be referenced when determining compliance in the absence of an applicable EU ambient air quality standard. The relevant statutory guidance can be obtained from the following sources:

- Danish C-values (as a 99th%ile) outlined in Danish EPA's Environmental Guidelines No. 1, 2002 Guidelines for Air Emission Regulation Limitation of air pollution from installations(78).
- Instructions on Air Quality Control – *TA Luft* from the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety Technical(79),
- Environmental Assessment Level (EAL) based on the Health & Safety Authority publication 2007 Code of Practice for the Safety, Health and Welfare at Work (Chemical Agents) Regulations 2001 (S.I. No. 619 OF 2001). The EAL should be derived using the approach outlined in Appendix D of UK Environment Agency "IPPC H1 - IPPC Environmental Assessment for BAT"(23). The guidance outlines the approach for deriving both short-term and long-term EALs. In relation to the long-term (annual) EAL, this can be derived by applying a factor of 100 to the 8-hour Occupational Exposure Level (OEL). The factor of 100 allows for both the greater period of exposure and the greater sensitivity of the general population. For short-term (1-hour) exposure, the EAL is derived by applying a factor of 10 to the short term exposure limit (STEL). In this case, only the sensitivity of the general population need be taken into account as there is no need for additional safety factors in terms of the period of exposure. Where STELs are not listed then a value of 3 times the 8-hour time weighted average occupational exposure limit may be used(23).
- Appendix D of the UK Environment Agency "IPPC H1 - IPPC Environmental Assessment for BAT" (Environment Agency, 2003)(23),

Where no standards / guidelines are identified from the above sources, WHO guidelines, US standards or standards derived from International Health & Safety (such as OSHA) limit values may be referenced:

- World Health Organisation (WHO) Air Quality Guidelines Global Update (2005)(80) and WHO Air Quality Guidelines For Europe (2000)(81) for those pollutants not covered in the 2005 publication.
- USEPA National Ambient Air Quality Standards(82),
- US Department of Labour Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs)(83).

When modelling unidentified / semi-quantified mixtures of volatile organic compounds (VOCs), a worst-case approach may be to assume that all emissions are in the form of benzene. Where this indicates an exceedance of the EU ambient air quality standard, a more detailed assessment will be required in order to determine the main constituents of the mixture and thereafter to assess whether compliance is being achieved with the relevant standards or guideline values for these constituents.

APPENDIX L - Glossary of Terms

Advanced models:	Dispersion models that are based on modern scientific theories and complex mathematical formulations. They can assess multiple sources, complex terrain and detailed meteorological conditions.
Boundary layer:	The boundary layer is the lowest layer of the atmosphere in contact with the earth's surface capped by a stable layer of air. It is height varies both spatially and with time.
Briggs plume rise equations:	Set of equations prepared by Briggs to describe the momentum and buoyancy effects on plume rise.
Friction velocity:	A parameter which describes the frictional forces per unit density acting on an air mass as it interacts with the surface of the earth.
Froude Number (Fr):	A dimensionless measure of atmospheric stability used to characterise the flow over hills. Low values of Fr (<1) lead to flows around hills whilst larger values (>1) lead to flows over hills.
Fumigation:	Mixing downward of an elevated plume from a stable layer into a turbulent mixed layer that has grown into the plume.
Gaussian plume models:	Class of dispersion models that assume both vertical and horizontal dispersion is represented by a Gaussian or normal distribution around the plume centreline.
Lagrangian puff models:	Class of dispersion models that assume dispersion can be represented by a series of puffs which are tracked in space by a moving coordinate system.
Obukhov length:	A parameter which defines the relationship between dynamic, thermal and buoyant processes in the boundary layer. It is used to calculate turbulence in the boundary layer.
Pasquill-Gifford (P-G) stability class:	Set of six separate categories to define atmospheric stability based on the meteorological parameters of insolation (incoming solar radiation), wind speed and cloud cover.
Plume rise:	Increase in altitude of plume resulting from its initial momentum and buoyancy.
Screening models:	Dispersion models that use a simplified representation of atmospheric dispersion for the conservative assessment of single sources.
Similarity theory:	Theory by which non-dimensional relationships between meteorological parameters are used to calculate a vertical profile of boundary layer turbulence.
Surface heat flux:	The heat flux between the surface of the earth and the atmosphere and which is typically positive during the day and negative at night.