5 Meteorology: A Critical Input

5.1 Sensitivity of models to meteorological data

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

The meteorological data requirements for steady-state Gaussian-plume models and advanced dispersion models vary considerably. Steady-state Gaussian-plume models require meteorology data from a single surface station. They assume that the single station data are applicable to the whole modelling domain up to the top of the boundary layer and that conditions do not vary with height.

Advanced dispersion models – including puff, particle and grid models – allow meteorological conditions to vary across the modelling domain and up through the atmosphere. This is a much more complex situation than for steady-state modelling and thus requires much more complex meteorological data. Because meteorological sites do not provide the relevant data at every point in the modelling domain, a meteorological model is used to predict and provide the meteorological variables at sites where information is not available. The advanced dispersion model then uses this *pre-processed* meteorological data for analysis.

Because the meteorological data requirements vary greatly between these two model types, the choice of which dispersion model to use can depend on questions regarding the expected meteorological conditions. The question, Will the meteorological conditions be uniform across the modelling domain? (or can they be approximated this way?) needs to be answered. You therefore need to consider the:

- boundary layer structure
- atmospheric turbulence
- modelling domain topography
- mesoscale meteorology (air-pollution meteorology).

There is a range of options for collecting and processing land-based meteorological data, including surface meteorological stations, tethered balloons, radiosonde upper air balloons, manual observations, remote sensing systems (SODAR/RASS, Radar, Lidar) and satellites. Various meteorological processors are also available to process raw data into formats required by air dispersion models.

Recommendation 44

Meteorological data must be treated as a critical input for any modelling study.

Steady-state Gaussian-plume models require meteorological data from a single surface station.

Advanced dispersion models allow meteorological conditions to vary across the modelling domain.

5.2 Meteorological data for steady-state Gaussian-plume models

Steady-state Gaussian-plume models require meteorological data from a single site. These data requirements can be met by three approaches, which are discussed in order below. The use of each approach will strongly depend on the:

- meteorological data available
- purpose for which the model is being used
- scale and significance of the potential effects of the discharge
- accuracy of information and level of detail required by the regulatory authority.

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

5.2.1 Screening meteorological data

As a first step and when worst-case events are of primary concern, it is generally recommended to use a standard screening meteorological data set as an initial air dispersion modelling assessment. Most commercially available models such as AUSPLUME or ISCST3 supply screening data sets with the model.

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

There are several limitations to these data. They can only model one-hour averages, not longer time-averaging periods such as eight hours, 24 hours or annual averages. This means that certain contaminants that have ambient guidelines for longer periods – such as PM_{10} (24 hours) – cannot be directly assessed using a screening data set. However, the model CTSCREEN, which comes with a screening meteorological data set, can provide estimates of 24-hour averages.

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

Screening meteorological data sets should therefore not be used for:

- averaging periods longer than one hour
- PM_{10} sources that are likely to produce significant downwind concentrations
- frequency assessment of pollution events
- airshed sources.

Recommendation 45

Screening data sets should only be used to gain a ‘first cut’ estimate of the magnitude of the maximum ground-level concentration for a particular source.

When a screening data set is used, the modeller must ensure it contains mixing heights and stability classes which realistically represent the location being modelled.

To estimate the ‘worst-case’ scenario, all other model inputs, such as emission rates, must be selected and shown to produce ‘conservative’ results.

5.2.2 Ready-made, site-specific data sets

When screening meteorological data cannot be used, it may be appropriate to use ready-made, site-specific meteorological data sets for modelling. These situations include those when a screening data set does not:

- provide sufficient accuracy
- meet the criteria of the ambient air quality requirements of the local council
- suit the source or type of pollutant being modelled (e.g. PM_{10} from a large coal-fired boiler).

Some urban and regional ready-made meteorological data sets have been produced for some regional councils and are also available for a number of the larger cities in New Zealand (see Appendix B). These regional councils should be able to provide advice on the availability and appropriateness of any ready-made site-specific data set for a specific modelling project.

Some private consultants have also produced site-specific data sets. Normally this data is carefully guarded intellectual property or owned by their clients. But depending on the task for which it is intended and the amount you are prepared to pay, this source of data may be worth exploring. Again the relevant regional council should be able to provide advice on what, if any, data has been produced by consultants for a specific area. The data sets developed by consultants normally cost between $1000 and $5000.

5.2.3 Developing a site-specific data set

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

The predecessor to this Guide is the document *Guidelines for the use of Dispersion Models* (NIWA, 1998). Part 2 of this document provides an overview on the use of meteorological data as input for Gaussian-plume dispersion models. It also contains detailed descriptions of some of the methods used to calculate derived meteorological parameters. While Part 2 of the original modelling guideline provides a useful introduction to the use of meteorological data in modelling, recent developments in meteorological modelling have rendered some of the detail out of date. The following sections provide current recommended practices.

Developing a meteorological data set can be expensive and time-consuming. Depending on the complexity of the site, a degree of meteorological expertise may be required to make sure the data are accurately representing the conditions experienced at the site. It is recommended that if the data are to be used as part of an AEE, they are put through a thorough quality assurance process and/or peer reviewed before use.

The collection of site-specific meteorological data has been fully covered in the documents *On-site Meteorological Program Guidance for Regulatory Modelling Applications* (US EPA, 1987) and Part 51, *Guideline on Air Quality Models* (US EPA, 1999). The former provides details on site location, recording mechanisms, data communication, sampling rates, system accuracies, data handling, quality control and treatment of missing data. It is recommended that this guidance be adopted as best practice for the collection and processing of meteorological data for use in dispersion modelling applications. This is consistent with the approach taken in the *Good Practice Guide for Air Quality Monitoring and Data Management* (Ministry for the Environment, 2000b).

When producing a site-specific data set there are generally two sources of data that can be used: data collected on site, or data collected from an existing nearby source.

a Data collected on site

A meteorological station should be located away from the influences of obstructions such as buildings and trees to ensure that the general state of the environment (wind direction and temperature) is best represented. It is recommended that you use a 10 m high mast for measuring wind direction and speed and temperature differentials. However, where the mast is located in good free-flow conditions and there are height restrictions from local council bylaws, a 6m high mast can be used.

For major industrial sources with tall stacks, or a site within a complex terrain environment, higher monitoring masts (30 m and higher) are recommended to adequately monitor lower boundary-layer wind and temperature profiles. It may be necessary for these situations to supplement or even replace a tall mast with monitoring via remote sensing instruments such as SODAR/RASS or tethered-sonde systems.

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

- temperature
- temperature difference (between 1.5 m and 10 m or higher)
- relative humidity
- wind speed

- wind direction
- solar radiation.

While all the above variables provide valuable information for modelling, the most important variables are wind speed and direction, and temperature. Setting up a station to record and log these three parameters costs approximately $12,000 (in 2004). There will also be relatively small additional costs associated with site maintenance and data management.

Depending on what instrumentation is employed on site, the data collected may need to be supplemented with the following off-site data from the National Institute of Water and Atmospheric (NIWA) Climate Database (CLIDB) system:

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

When developing a meteorological data set, the representativeness of the data set must be assessed, and demonstrated, in terms of climatic means and extremes. This can essentially be established in two ways: by undertaking long-term (three to five years) monitoring of on-site data collection, or by establishing correlations between on-site data, climatic averages and regional extremes. Average climatic conditions for the region can be obtained from NIWA's CLIimate DataBase (CLIDB) http://www.niwa.cri.nz/services/clidb/.

b Data from locations removed from but close to the site

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

c Where to get raw data from

The three principal sources of meteorological data are:

- Climate Database (CLIDB)
- New Zealand Meteorological Service
- regional councils, which operate ambient air quality monitors.

The Climate Database (CLIDB) (http://www.niwa.cri.nz/services/clidb/) is administered by NIWA in Wellington. Raw data can be downloaded if you are a registered user and familiar with structured query language (SQL). Otherwise NIWA CLIDB staff can download data for an administrative fee. Data are available through a subscription-based web service (CliFlo). Ad hoc or complex data requirements can be requested via the website's 'climate-enquiries' link.

5.2.4 Limitations associated with developing meteorological data sets

Limitations associated with developing meteorological data sets include the treatment of missing data and calm or stagnant conditions. These require careful consideration.

a Calms

Gaussian-plume models assume that concentrations of pollutants are inversely proportional to wind speed, therefore concentrations become unrealistically large as wind speeds approach calm conditions. Two of the commonly used Gaussian-plume models deal with calms in the following manner.

- AUSPLUME calculates pollutant concentrations for a minimum wind speed of 0.5 m/s. Wind speeds in the model's meteorological data input file that are less than 0.5 m/s are substituted with a wind speed of 0.5 m/s.
- ISCST3 calculates pollutant concentrations for a minimum wind speed of 1 m/s. However the criterion of l m/s wind speed is referenced to the point of release (i.e. stack height). Wind speeds generally increase with height above the ground and ISCST3 recognises this. Consequently, depending upon the height of the stack and stability conditions, the wind speeds at point of release may be higher than those recorded in the meteorological data input file (which are generally taken at a reference height of 10 m). ISCST3 does not calculate pollutant concentrations for wind speeds of less than 1 m/s at release height and assigns the concentration for a wind speed of 1 m/s to any hours in the data set where the wind speed is between 0.5 and 1.0 m/s. Any wind speed less than 0.5 m/s is treated as invalid data.

Neither model treats low wind speeds in a realistic manner and effectively throws away worst-case dispersion conditions for many types of sources. If all hours of wind speed less than 0.5 m/s or 1.0 m/s were treated as invalid/missing data and removed from the data set, this may distort the frequency distribution of predicted concentrations. For example, if worst-case conditions are F stability with wind speeds of 0.5 m/s or less and 1% of the data is treated as invalid/missing, then the 99.9 or 99.5 percentile concentration may be very much lower than it would be in reality. For this reason it is recommended that when using steady-state models, all wind speeds less than 0.5 m/s contained in the meteorological data be set to 0.5 m/s. The amount of adjusted wind speed data must be quantified when presenting the modelling results and the potential implications of the data adjustment must be addressed in the assessment.

The potential effect of low wind speeds on assessments undertaken using Gaussian-plume models depends quite strongly on the nature of local wind flow, and the accuracy (or otherwise) of the hourly average wind direction. In some situations, the wind direction may be steady at low wind speeds (e.g. cold drainage flow down-slope or a land breeze), while in other situations the wind direction may be highly variable over a short time scale. In the former situation, the hourly average wind direction may be quite accurate (i.e. the wind direction is quite steady), and the low wind speed prediction from the Gaussian-plume model may be reasonable. In the latter situation, the hourly average assumption results in an over-estimation as the wind direction meanders over a wide range. At any particular site either situation can probably arise at different times. This situation emphasises (again) the value of local meteorological data.

If calm conditions are recognised as a potential issue for a specific site, an advanced model may be used as these still operate no matter how low the wind speed. CALPUFF assumes that hourly average winds below 0.5 m/s are calms and uses its specific algorithms to deal with them as such. Particle dispersion models, such as that included in TAPM, may give a better picture of dispersion in calm conditions, as they can account for sub-hour fluctuations in the wind and particle distributions are not restricted to being Gaussian in shape. However, there is still some debate on these issues, which remain unresolved.

Recommendation 46

When modelling with steady-state models, all wind speeds less than 0.5 m/s contained in the meteorological data set must be:

a) quantified and reported when presenting modelling results

b) set to 0.5 m/s before modelling.

The implications of not being able to model calm conditions must be addressed in the assessment.

Where maximum concentrations are predicted for low wind speeds, local meteorological monitoring is highly desirable. Use this data to resolve questions about the variability of wind direction and the accuracy (or otherwise) of the hourly average wind direction.

b Missing data

Most meteorological processing programs and air dispersion models require a full data set of all parameters for all hours. Missing data must be replaced with synthesised data to ensure that the air dispersion models can function. Where there are only one or two hours of missing data, linear interpolation of the data is acceptable.

In New Zealand, with many remote automated surface weather stations, longer periods of missing data (in the order of weeks) may occur. For periods of up to seven days, synthesised averages from a longer-term record of the station may be substituted into the data set. For continuous periods of longer than seven days, the data should be considered to be missing and the length of the data set reduced by the length of the missing data. For example, with three weeks of continuous missing data, the total length of the data would cover 49 weeks instead of a standard 52 weeks. It is important, however, to ensure that an adequate coverage of all seasons is obtained within the data.

Recommendation 47

All missing or synthesised meteorological data should be clearly documented and discussed in the method.

Periods of missing data that are less than seven days in length may be replaced with synthesised data produced from long-term seasonally adjusted records.

Periods of missing data that are longer than seven days in length must be recorded as missing data.

5.2.5 Derived meteorological parameters

For steady-state plume modelling there are two key meteorological parameters that are not likely to be directly measured and are required for single-station meteorological files only: stability and mixing height.

a Stability classification schemes

Atmospheric stability is a measure of the propensity for vertical motion and hence is an important indicator of the likely magnitude of pollutant dispersion.

A simplified measure of stability was developed by Pasquill (1961) and later modified by Gifford. This is called the Pasquill-Gifford (PG) Stability Classification and is based on a fairly restricted set of measurements of an unspecified averaging time. The measurements were made in the 1950s. This classification consists of six classes, which include A (extremely unstable), B (moderately unstable), C (slightly unstable), D (neutral), E (slightly stable) and F (moderately stable) (see Appendix A).

In 1967 Turner developed a classification scheme based on the original Pasquill-Gifford scheme. This consists of seven classes including 1 (extremely unstable), 2 (unstable), 3 (slightly unstable), 4 (neutral), 5 (slightly stable), 6 (stable) and 7 (extremely stable).

These classification schemes assume that stability in the layers near the ground are governed by convective fluxes from solar radiation (day), cloud cover (night) and mechanical fluxes from wind speed. Although there are more superior dispersion coefficient schemes, most models offer the P-G dispersion coefficient scheme due to its long and relatively successful history of use.

The Pasquill-Gifford stability classification scheme can be used unless an alternative method can be shown to produce more accurate results.

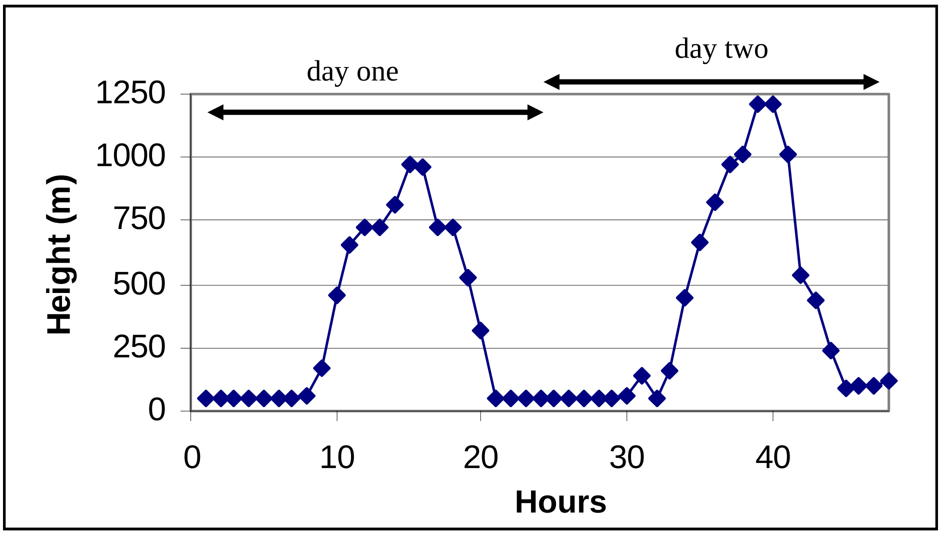
Recommendation 48

Full details of methods used to assign stability classes using routinely monitored meteorological data are given in US EPA, 1987.

b Mixing height

The mixing height or mixing depth is the height to which the atmosphere is uniformly mixed. Mixing height is determined by either upper atmosphere temperature inversions or wind shear (changes in wind speed with height). Mixing heights have a diurnal variation and rapidly change after sunrise and at sunset (Figure 5.1). Research shows an inverse relationship between pollutant concentrations and mixing height, so mixing height is often used as, and is a critical guide of, the pollution potential in an area (Oke, 1987). Dispersion model predictions can be highly sensitive to changes in mixing height.

Figure 5.1: Typical diurnal mixing height variation over two days



If a plume penetrates up through, or is released above, the mixing height, the pollutants will be trapped aloft and their effect will not be observed at ground level. If a plume is trapped within a shallow mixed layer the vertical dispersion will be limited and high ground-level concentrations are likely to occur.

Four methods that are commonly used to determine mixing height are:

- derivation from upper air data (e.g. radiosonde measurements)
- ground-based remote sensing (e.g. Doppler SODAR)
- derivation from routinely measured surface meteorological data (e.g. using a US EPA meteorological pre-processor model such as RAMMET)
- using a prognostic meteorological model (e.g. TAPM, see section 5.3.2).

Determining mixing height is usually an expensive and complex task requiring considerable expertise and should therefore not be undertaken lightly. The uncertainty of mixing heights determined by the methods referred to above increases in the lowest level of the atmosphere. It is generally accepted that mixing heights determined to be less than 50 m contain a significant degree of uncertainty.

Recommendation 49

When mixing height data are required but not available, determine if the model results are sensitive to changes in mixing height by undertaking a sensitivity analysis of the model results to this parameter.

When it can be demonstrated that mixing height data are not a critical parameter, use data that are likely to be representative of the patterns expected in the area of interest.

When mixing height are a critical parameter, derive these data set using the following hierarchy of methods:

a) ground-based remote sensing
b) derivation from upper air data
c) derivation from routinely measured surface meteorological data
d) estimation using a validated meteorological model.

Set the minimum mixing height in a meteorological data set to 50 metres unless there is evidence to show that mixing heights of less than 50 metres do actually occur.

5.2.6 Meteorological conditions that Gaussian-plume models cannot account for

In situations of complex terrain or near coastal boundaries, meteorological conditions such as calms, coastal fumigation, sea/land breeze re-circulation, and mountain and valley winds can significantly affect the dispersion of pollutants. These meteorological conditions are highly complex in a spatial (vary quickly from place to place) and temporal (vary within periods of minutes rather than hours) sense.

Gaussian-plume models cannot account for these meteorological conditions adequately because of the steady-state formulation (which assumes uniform meteorological conditions) and their inability to retain a memory of the preceding hour’s emissions. The following examples highlight meteorological conditions that Gaussian-plume models cannot adequately simulate and for which an advanced dispersion model should be used instead.

a Calm and low wind speed conditions

Under stable, high-pressure synoptic (large-scale) weather conditions, calm conditions often occur near the ground, especially at night and early morning. These stable conditions can often result in elevated pollution episodes as vertical and horizontal mixing of the lower boundary layer is inhibited. Calms are of particular concern when dealing with sources that release contaminants close to the ground or when looking at airshed systems. Gaussian-plume models break down during low wind speed or calm conditions due to the inverse wind speed dependence of the steady-state plume equation, and this limits their application. How to deal with calm conditions when using Gaussian-plume models is discussed in section 5.2.5(a).

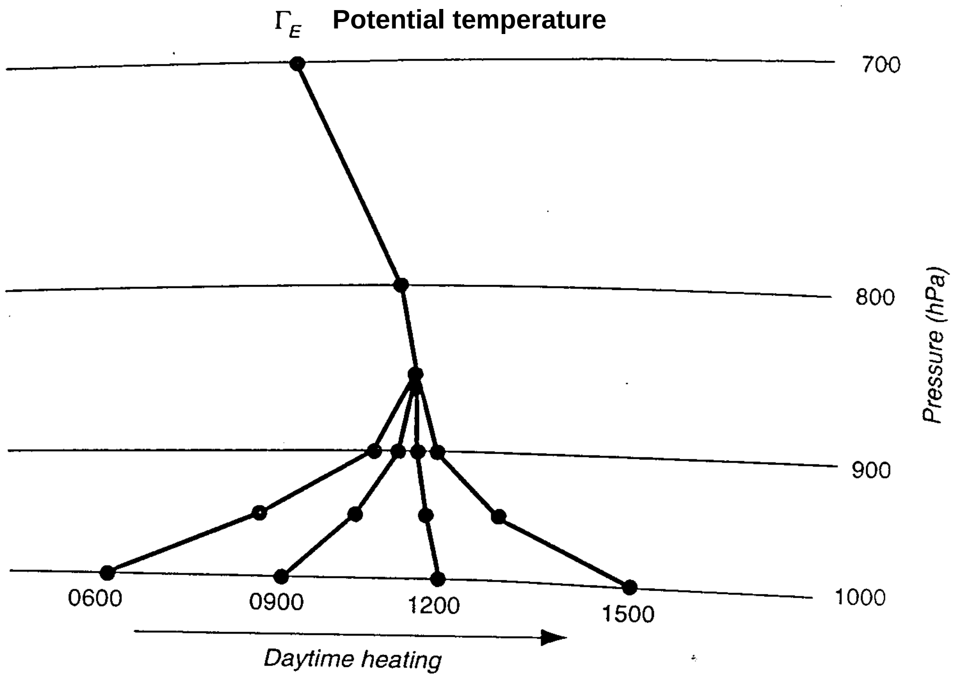
b Inversions

Temperature inversions are caused by a number of different mechanisms. Surface or ground-based inversions often occur on clear, cold nights when there are low wind speeds. Under these conditions the ground cools more quickly than the air immediately above it, causing a pool of cooler, more dense air to accumulate at ground level. These ground-based inversions occur frequently throughout New Zealand, especially in hilly terrain. If temperature inversions develop in a valley, pollutants can often be trapped under the inversion layer and result in high pollution episodes. The break-up of a surface inversion is shown in Figure 5.2, where the layer of air near the ground (at 1000 hPa) heats up during the day by radiative heating while the upper air temperature (above 900 hPa) remains relatively constant.

An advection inversion often occurs when warm air passes over a cooler surface, which can result in the development of a low-level inversion and the formation of ground-level fog. This type of inversion occurs less frequently in New Zealand.

A subsidence inversion or upper air inversion develops within a high-pressure system when the subsiding air is compressed and the upper air becomes warmer than the air below.

Figure 5.2: The break-up of a ground-based inversion during the day



Inversion conditions are difficult to simulate with Gaussian-plume models, due to associated low wind speeds (see section 5.2.7a), the appearance of multiple layers of pollution, and the difficulty of defining the mixing height.

c Fumigation during inversion break-up

Nocturnal ground-based and upper air inversions start to break up during the first few hours of sunlight as the net heat flux (heating of the surface by the sun) becomes positive. As the ground heats from below, convective mixing (heat transfer) takes place, effectively breaking up the ground-based inversion from below. The growing vertical eddies (caused by heating) mix the air above the surface inversion down to ground level, a process called inversion break-up.

Inversion break-up fumigation is the process whereby pollutants emitted above the inversion layer during the night are fumigated down to the ground during this break-up process. Inversion break-up fumigation is often associated with very high pollutant concentrations at some distance from the source. This process is fairly transient, taking place over tens of minutes and typically during mid-morning (Kerman et al., 1982).

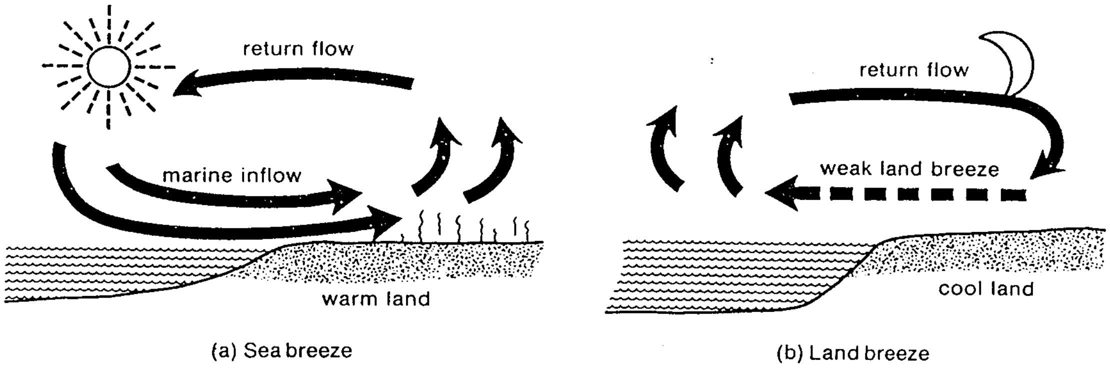
The transient nature of these events, and the difficulties that Gaussian-plume models have identifying different layers aloft and the interaction between layers, makes fumigation during inversion break-up an issue to be wary of when using these models. However, one Gaussian-plume model, SCREEN 3, the US EPA's screening version of ISC3, does incorporate code specifically written to enable it to provide estimates of maximum concentrations during inversion break-up.

d Sea- and land-breeze circulations

Because land surfaces heat and cool quicker than the sea or other water bodies, temperature gradients develop that can result in the generation of localised wind flows (Figure 5.3). A sea breeze develops during the day as the air over the land warms more quickly than the air over the sea. It rises, bringing in an onshore breeze, with a return flow aloft. At night the opposite occurs and a land breeze develops, flowing towards the sea under an area of subsidence.

Sea breezes are generally strongest during the day in summer and land breezes strongest during winter nights. They can both have significant effects on air quality over urban areas, as they are recirculating air currents that can return pollutants (instead of remove them) to an area from which they were released earlier in the day.

Figure 5.3: Sea and land breeze



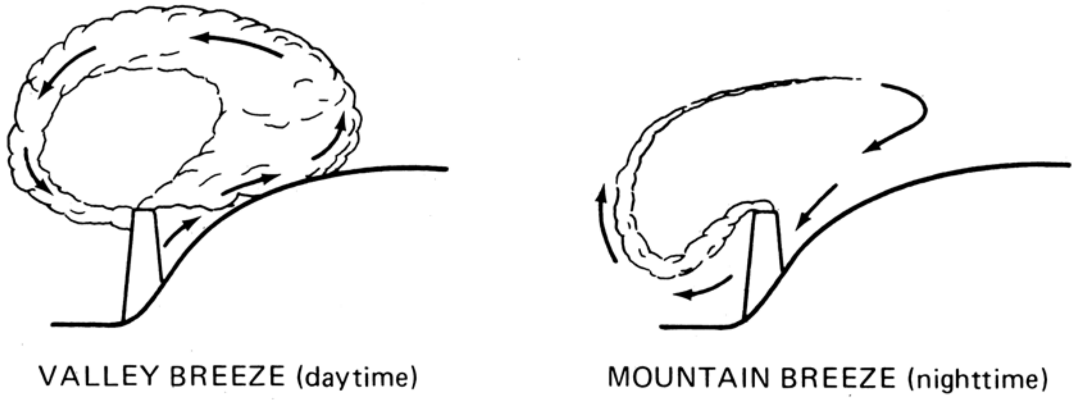
(a) Sea breeze (b) Land breeze

Source: Pendergast, 1984

e Mountain–valley winds

Mountain and valley winds are generated due to similar heating and cooling mechanisms to sea–land breezes. During the day the air above a slope is heated and becomes warmer than neighbouring air at the same height above sea level, but further above the ground. It rises due to convection, and upslope mountain winds occur (Figure 5.4). At night the mountain slopes cool more quickly than the surrounding air, and the cool air drains down the slope, generating valley winds. This heating and cooling often results in closed circulation patterns, which can trap and/or recirculate air pollution in the mountain–valley system.

Figure 5.4: Valley and mountain winds



Source: Pendergast, 1984

Recommendation 50

Where there are meteorological conditions that Gaussian-plume models cannot account for, an advanced model (which is more capable of handling these conditions) should be used.

5.3 Meteorological data for advanced dispersion models

Advanced dispersion models require more complex meteorological data than steady-state models. This includes inputs from surface networks (land and sea) and upper air stations. Because there will not be meteorological sites at every point on the ground in the modelling domain, and monitoring in the upper air (anything above the height of a tower) is normally very sparse, meteorological models must be used to provide this ‘missing data’.

There are two different types of meteorological model that can be used to provide a three-dimensional grid of meteorological data:

- diagnostic wind models (DWM), which interpolate and/or extrapolate meteorological observations
- prognostic models, also known as a ‘mesoscale’ models.

The meteorological model outputs are then used to drive a dispersion model.

Meteorological models can either form part of an air dispersion modelling system (e.g. CALMET provides meteorological fields for CALPUFF, RAMS for HYPACT, and TAPM calculates both the meteorology and dispersion), or they can be stand-alone. Prognostic models (from mesoscale to global scales) are used to provide national weather forecasts. RAMS is used worldwide for this purpose; LAPS – whose analyses are used to drive TAPM – is used in Australia. The NZ Meteorological Service uses MM5 for mesoscale weather forecasts.

Meteorological models of the type described in this section – and their associated dispersion models – have rarely been used in New Zealand for regulatory impact assessments, largely because:

- the models have not been user friendly and needed large computing resources to run them
- the network of meteorological stations for input data to a diagnostic model (especially upper air) is relatively sparse
- the format for data storage is sometimes not compatible with that required by the model.

More recently a number of advanced dispersion models have been released that are much more user friendly. Efforts are always being made by developers to enable models to run faster, and with increased computing power available it is becoming feasible for all users to run these models on a modern personal computer. It is the rapid increase in computing power over recent years that has resulted in an increase in the number of people using these tools.

Examples of diagnostic and prognostic meteorological models are provided in the following two sections. Recommendations outlining which meteorological models to use in the New Zealand situation are given in section 5.3.5.

5.3.1 Diagnostic meteorological models

Diagnostic meteorological models use data from available locations and assign values to the meteorological variables throughout a three-dimensional grid by interpolation and extrapolation. The conservation of mass principle is applied throughout the process. The term ‘diagnostic’ is used because the input data and model results are for the same time period. Diagnostic models are not predictive, and their calculated fields for each time interval do not depend on fields at previous times. The model’s output is a data file in a format required by a particular air dispersion model.

An example is CALMET, the pre-processor to CALPUFF. In recent years CALMET has been increasingly used in the USA and Australasia, and is used here to illustrate the features of a diagnostic meteorological model.

The CALMET meteorological model (Scire et al., 2000) is a diagnostic meteorological model developed as a component of the CALPUFF modelling system for use in air quality applications. CALMET in its basic form is designed to produce hourly fields of three-dimensional winds and various micro-meteorological variables based on the input of routinely available surface and upper air meteorological observations only. CALMET consists of a diagnostic wind field module and micro-meteorological modules for over-water and over-land boundary layers.

The diagnostic wind field module uses a two-step approach to the computation of the wind fields (Douglas and Kessler, 1998). In the first step, the initial-guess wind field is adjusted for terrain effects to produce a step 1 wind field. The second step consists of an objective analysis procedure to introduce observational data into the step 1 wind field to produce a final wind field, the step 2 wind field. Some of the advantages and disadvantages of this model are detailed below.

Advantages of CALMET

- Observations can be incorporated into the model, to produce realistic meteorological fields.
- CALMET can reproduce fine-scale effects (down to a couple of hundred metres' resolution) and still maintain efficient model run times on a personal computer.
- Output from the prognostic meteorological models such as MM5 and TAPM can be incorporated into the CALMET run, providing information in data-sparse regions. This combined approach is the preferred way of operating CALMET.

Disadvantages of CALMET

- The CALMET/CALPUFF system is technically more advanced than a plume model and is perceived as being difficult to regulate and complex to use.
- Routine meteorological data are sparse in New Zealand.
- There are potentially extra costs of running CALMET.

Summary

With regard to *ease of use*, CALPUFF can be run in a steady-state mode using the same meteorological data that are required to run AUSPLUME or ISCST3. The minimum requirements for CALMET are similar to those for the steady-state models. An ISCST3 or AUSPLUME meteorological file can be used to drive CALPUFF, but again there is the option for a more refined treatment when it is necessary and the data are available.

Costs to industry may be higher for a full CALMET/CALPUFF analysis than a simple steady-state analysis. In many cases, though, the differential is very small compared to other fixed costs of a project, and the differential tends to decrease with increasing modeller experience. Also, a more accurate answer can mean large savings in a project, and in some cases can make the difference between obtaining approval for a project or being rejected. Industry will also save costs from the model's ability to handle multiple effects within one model framework; i.e. once set up the modeller can model anything from long-distance visibility to aqueous phase chemistry to plume visibility applications, without requiring the services and set-up costs of another model.

5.3.2 Prognostic meteorological models

Prognostic models are driven by large-scale synoptic analyses and numerically solve the equations of atmospheric dynamics to determine local meteorological conditions. They do not require local meteorological data to run, although if data are available they should be compared with model results to validate the model. Prognostic models are able to represent all scales, from global down to features on scales in the range 1–10 km. Most are run in a nested format with the outer domain covering distances in the order of 500–1000 km – the regional scale.

All domains are initialised using analyses from global or limited-area models, usually run by national weather services. These are provided by many forecasting agencies or similar institutions, such as the US National Meteorological Center, the European Centre for Medium-Range Weather Forecasts, the UK Meteorological Office, or the Australian Bureau of Meteorology. The outer domain is also driven at its boundaries by the global or limited-area models as the run progresses – this feeds in the effects of weather systems to the domain of interest. The prognostic models describe the three-dimensional fields of temperature, wind speed and direction, and moisture through the region at high spatial resolution.

Prognostic models all contain realistic dynamical and physical formulations, and potentially produce the most realistic meteorological simulations for regions where data are sparse or non-existent. The high resolution needed for regulatory assessments means that these models have historically been seldom used as regulatory models. The computing costs of long-term simulations have been prohibitive, although more recently this is less true. And, if local meteorological data are absent, the use of a prognostic modelling system could be a sensible option as part of a regulatory assessment.

RAMS is the most commonly used prognostic meteorological model in New Zealand (Wratt et al., 2001), followed by MM5, ARPS, and (more recently), TAPM.

a RAMS and MM5

RAMS and MM5 are three-dimensional, non-hydrostatic prognostic mesoscale models. MM5 is the fifth-generation NCAR/Penn State Mesoscale model. The model includes a multiple-nesting capability, non-hydrostatic dynamics and four-dimensional data assimilation (Dudhia et al., 1999). MM5 is free to users, while RAMS is subjected to licensing costs. Both models enjoy widespread use throughout the world, are well supported, continually under development, have been used in many studies, and appear regularly in the scientific literature. The main advantages and disadvantages of these models are detailed below.

Advantages of RAMS and MM5

RAMS and MM5:

- have the ability to assimilate local meteorological data
- have realistic dynamical and physical formulations, suitable for simulations in New Zealand’s complex environment
- can produce realistic meteorological fields in data-sparse regions
- are flexible enough to couple output meteorological fields to dispersion model runs at any resolution (e.g. RAMS coupled to HYPACT).

Disadvantages of RAMS and MM5

RAMS and MM5:

- have relatively high computational demands
- require a large amount of user knowledge and expertise to produce reliable and convincing results
- do not themselves include dispersion models, and the associated dispersion models do not necessarily comprise all of the features required for regulatory assessments (e.g. building effects).

b TAPM

At present, most prognostic models require significant computer resources to run. They also describe a comprehensive collection of meteorological phenomena and are widely used in meteorological research. However, some features that contribute significantly to the computational cost of mesoscale modelling are not important for air quality simulations, such as gravity waves and complicated microphysical processes. Careful formulation of the model dynamics so as to omit or filter out these features can increase the run speed, enabling longer runs to be contemplated for regulatory applications. This has been done with the CSIRO's TAPM.

TAPM is a PC-based three-dimensional prognostic meteorological modelling system, including various dispersion modules, as described in section 2.2.2. TAPM has a GUI that allows the user to set up and run the model under the Windows operating system. It connects to databases of terrain, vegetation, soil type, sea surface temperature and synoptic-scale meteorological analyses for Australia and New Zealand, as well as most regions throughout the world. TAPM is driven by six-hourly synoptic analyses at approximately 75 km resolution. This database is derived from LAPS analysis data from the Bureau of Meteorology.

Advantages of TAPM

- It is easy to use and completely self-contained, with good visualisation of model results.
- The model output is easy to convert for input into other models, such as CALMET, AUSPLUME, DISPMOD and ISCST3.
- As for any prognostic model, it requires no local data to run, although it has the ability to assimilate local surface meteorological data.
- It is designed to run on a modern personal computer.
- Describes the effects of point, line and volume sources, simulates the effects of buildings on dispersion, and simulates chemical reactions between pollutants.
- Resolution of the pollution dispersion models can be higher than that of the meteorological model – and will usually need to be for regulatory assessments.

Disadvantages of TAPM

- Although easy to use, a high level of understanding of boundary-layer meteorology and pollution dispersion is needed, as with all prognostic model systems, to produce meaningful results.
- The maximum horizontal resolution of the meteorological model component of TAPM is of the order of a 1 km grid-size. If meteorological features are expected, or geographical forcing is present at smaller scales, then the user should take care. Although assimilation of meteorological data is possible, care must be taken to ensure that the meteorological data are representative of the scales modelled by the meteorological model.

5.3.3 Prognostic model output as inputs to Gaussian-plume models

Some prognostic meteorological models produce output data in a format that can be used by plume models. Prognostic model results may be extracted at a single location (the site of pollution emissions) in a format compatible with, say, AUSPLUME or ISCST3, and treated as pseudo-observations for input to the dispersion models. This is a possible alternative if there are no site-specific observations, and has the advantage that there would be no missing data. The pseudo-data would also be compatible with CALPUFF running in a single-site mode. TAPM has options to produce meteorological output compatible with most commonly used Gaussian-plume models.

However, extracting results from a single point to run a plume model ignores many of the advantages of undertaking sophisticated – and more realistic – meteorological modelling, as most information in the prognostic model results would never be used. If a model such as TAPM is being run to produce the meteorological information, then it can be run as a dispersion model at little extra cost.

Care should also be taken when extracting only the mixing height from a single point. Although the model mixing height should be consistent with other model parameters at that location, it may not be consistent with observed parameters (e.g. wind and temperature), which are being used as inputs to the plume model. It would be more realistic to derive the mixing height from meteorological observations.

The practical advantage of extracting single-point meteorological data for a plume model is that the meteorological model need only be run once, no matter how many dispersion model runs are required. As TAPM is a self-contained meteorological and dispersion model, with the two processes running at the same time, the meteorology has to be re-run for each dispersion model case, and this is relatively computer resource intensive. However, other meteorological and dispersion models (e.g. RAMS/HYPACT or CALMET/CALPUFF) carry out the two processes separately. The meteorological data need only be calculated once and this consideration does not apply.

Recommendation 51

Prognostic model output should only be used as meteorological input data for Gaussian-plume models when:

a) it is appropriate to use a Gaussian-plume model for dispersion

b) there is no other source of meteorological data available.

However, using the TAPM meteorological output in a simple (quick to run) dispersion model can be attractive when you want to quickly test a wide range of options.

5.3.4 A combined prognostic/diagnostic approach

Both the prognostic and diagnostic approaches to meteorological modelling have advantages for the production of realistic meteorological fields for input to dispersion models, as follows.

- Prognostic models do not need local meteorological observations to run, so can simulate the meteorology of regions where few data are available.
- Diagnostic models can incorporate available measurements, and – provided the measurements are interpolated realistically – can potentially produce meteorology close to that observed (indeed, at the monitoring sites the modelled meteorology should be exactly the same as that observed).

Two variations on these approaches may be identified in which each model type incorporates the beneficial features of the other.

a Data-assimilating prognostic models

Prognostic models can take advantage of local meteorological data by the process of meteorological data assimilation. There are several ways of accomplishing this. One common method is known as ‘nudging’. Essentially, the prognostic model solution is forced towards the observations during the model run. At best, the model solution is already close, so the forcing is small – hence the term ‘nudging’. Nudging can have beneficial effects on the model solution, but must be used carefully. For example, the local meteorological data input to the prognostic model should be representative of the observed meteorology on scales resolved by the prognostic model. If the monitoring site is in complex terrain which is not resolved by the prognostic model grid, then its data should not be assimilated.

b Prognostic model output as input to a diagnostic model

Diagnostic models may be run in data-sparse areas through the incorporation of output from a prognostic model. The prognostic model provides a ‘first-guess field’, which is then modified by the diagnostic model to take account of terrain or land-use features that are at a smaller spatial scale than the terrain used by the prognostic model. The main purpose of this approach is to increase the horizontal resolution of the meteorological fields, which is necessary if there are important terrain or land-use features at the higher resolution. The procedure is far less computationally demanding than running a prognostic meteorological model (with or without data assimilation) at sub-km resolutions.

It is worth noting that:

- approaches (a) and (b) are not new, but they are discussed here as practical approaches to combining results from prognostic meteorological models (which simulate the atmospheric dynamics according to physical laws) with available meteorological observations
- the combined approaches work in both data-sparse and data-abundant regions
- most, if not all, prognostic models have data assimilation routines, so they may be used in approach (a)
- diagnostic models such as CALMET are set up to combine prognostic model output with meteorological measurements in approach (b)
- meteorological observations may be used twice, being both assimilated into the prognostic model run and used in the objective analysis stage of the diagnostic model run.

The choice between approaches (a) and (b) involves considering the best resolution that may be practically attained in a long-term prognostic model simulation. This should be high enough to resolve the important meteorological features which can only be simulated by a prognostic model, such as land and sea breezes, and developing cyclones and fronts. If this is sufficient to resolve terrain and land-use effects on the local meteorology, then approach (a) is appropriate. If there are, say, terrain-forcing effects, such as blocking, channelling or slope flows which are not resolved in the prognostic simulation, then these may be incorporated using a diagnostic model; that is, following approach (b).

It is important to note that the choice between (a) and (b) and the choice of model resolution (for both prognostic and diagnostic) depends on meteorological considerations only. The resolution of the dispersion model is independent of the resolution of the meteorological model(s), and is generally equal to or (much) higher than the resolution of the input meteorology.

These approaches, despite their potential to produce realistic mesoscale meteorological features (which have important consequences for pollution dispersion), have not been widely adopted in New Zealand. They are becoming more common overseas for regulatory impact assessments, and have been used worldwide for many years for scientific research.

Approach (b) involves combining the three-dimensional prognostic model output with meteorological observations (from the surface and from vertical profiles) in a diagnostic model. A variation on this uses a set of key, user-selected vertical profiles, extracted from the prognostic model results, and used as if they were observations in the diagnostic model. The diagnostic model extrapolates to provide three-dimensional fields. The extracted profiles are used in place of the full three-dimensional prognostic model fields. However, three-dimensional model output can occupy an extremely large amount of disk space – files need to be as text rather than binary format so they can be read by a different model. For example, TAPM allows this variation of approach (b) in the extraction of profiles for input to CALMET as pseudo-data.

However, the latest version of TAPM (v 2.0) allows output of the full three-dimensional meteorological fields (as text), which may be converted by the user and read by CALMET.

c Hazards associated with combining model results with observations

Careful checking needs to be carried out with the approach described in section 5.3.4a. Data assimilation works well if the model prediction at the data point is already close to the observation at that location. If this is not the case, the model solution at surrounding and downwind grid points can become nonsensical.

It must be assumed that over a 12-month period the prognostic model will not predict some days well in (probably) all regions. If the intention is to run a dispersion model for 12 months and examine annual statistics, it may be safely assumed that the meteorological model will predict the right types of weather and at the right annual frequency, even if not on the correct day all the time. It is perhaps safer to use the observations to validate the modelled meteorology, rather than assimilating them and potentially generating unrealistic model results. Extra care must be taken if the dispersion modeller wishes to use the meteorological model to simulate a particular day. In that case, the meteorology has to be correct and must be validated against suitable observed data.

Similar considerations apply when adopting the approach in section 5.3.4b. If the prognostic model output used in the initial-guess phase of CALMET's wind field calculation differs from the observations used in the subsequent objective analysis, the resulting wind field will be unrealistic. This can occur particularly if the prognostic model does not resolve terrain effects which are resolved by CALMET. If observations are plentiful, a more realistic wind field may be obtained without the prognostic fields as an 'initial guess'. If scarce, it could be safer to run CALMET in a 'no-observations' mode, where the wind field is a perturbation of the prognostic model output.

5.3.5 The future use of non-steady-state meteorological data in New Zealand

As indicated earlier in the document, an important difference between Gaussian-plume dispersion models and more advanced dispersion models is in their requirements for meteorological data. Advanced dispersion models require fully three-dimensional, time-dependent meteorological data (i.e. 'non-steady state'), which are provided by advanced meteorological models such as TAPM, MM5 and CALMET.

In New Zealand, the creation of non-steady-state meteorological data sets has been mainly carried out by scientists as part of research programmes, rather than consultants with more limited time and resources. This situation is gradually changing, as advanced models are steadily becoming more widely used. This is encouraging, as many dispersion-modelling exercises ought to be carried out using advanced models rather than Gaussian-plume models. Criteria for deciding the kind of model to use have already been discussed.

Once it has been decided that your project requires an advanced dispersion model – and therefore requires three-dimensional meteorological fields – there are several factors to consider when deciding on the most appropriate meteorological model. In other words, there are still some New Zealand-specific issues to address.

For one thing, many areas of New Zealand have very few surface meteorological data sites, and there are only three routine radio-sounding sites providing vertical profiles (Whenuapai, Paraparaumu and Invercargill). This poses a challenge when running a diagnostic wind model using observational data only.

New Zealand's complex terrain poses a different challenge for prognostic meteorological models. As already discussed, attempts at the combined prognostic/diagnostic approach may lead to problems when the prognostic model results are not consistent with observations.

The dispersion modeller, though acknowledging it is necessary, may still be daunted by the task of meteorological modelling. However, in time, as the modelling community in New Zealand becomes more experienced, the consequences of these issues will become better understood, and will be accounted for at the reporting stage. Also, meteorological models are continually improving, and in future they will be able to better handle meteorological conditions in complex terrain and coastal areas.

Finally, it is unlikely there will be an increase in the number of routine meteorological sites around New Zealand.

Recommendation 52

When carrying out non-steady-state meteorological modelling:

a) assess the availability of meteorological data in the region to be modelled
b) consult a topographic map of the region to gauge its geographical complexity
c) determine what spatial resolution is likely to be required
d) decide whether the required resolution is feasible in a prognostic model
e) consider the prognostic model approach if feasible, or else the combined prognostic/diagnostic approach
f) consider the diagnostic approach alone if meteorological data are abundant
g) take care when assimilating observations into a prognostic model in regions of complex terrain
h) take care when incorporating observations into the diagnostic stage of the combined approach in regions of complex terrain.

These recommendations give only a general indication, and modellers should be guided by their own experience and expertise.

If advanced modelling is necessary, but considered too onerous by the modeller, then the meteorological component should be contracted out, rather than avoided through the use of a Gaussian-plume model.

6 Reporting Modelling Results

6.1 Introduction

The main objective of a modelling study is usually to determine the significance of the effects of pollutants discharged from a particular source. The results must therefore be reported effectively and concisely in a manner suitable for the purpose for which they were produced. This means the results must be communicated in a way that can be understood by other people who may not be experienced in interpreting model output. There are two elements to this: first, to report the modelling results themselves in an easy-to-understand manner; and second, to evaluate the implications of the results in terms of the potential effects of the predicted ground-level concentrations on people's health and the environment (also in an easy-to-understand manner).

This section focuses primarily on the first part – making modelling results easy to understand. The second aspect – how to evaluate modelling results in terms of potential environmental effects and the national environmental standards – will be covered in the upcoming *Good Practice Guide for Assessing Discharges to Air*.

The key factors involved in reporting modelling results are:

- do not include large sections of data in a report, except as an appendix or electronic attachment
- always include information about the input data and how variations may affect the results
- discuss the accuracy of the modelling results
- prepare maps of the pollution contours, where useful
- indicate which factors are most influential in determining the peak ground-level concentrations.

6.1.1 Statistics

Most models allow results to be assimilated and reported in a variety of formats to allow statistical analysis. These include the maximum predicted concentration at each or any receptor, or up to the *n*th highest predictions, where *n* is defined by the user. *n* is chosen to provide commonly used percentile predictions (such as the 99.5 percentile, which is the highest ground-level concentration at each receptor after the highest 0.5% of predictions have been discarded). Tables of the 50 (ISCST3 and CALPUFF) or 100 (AUSPLUME) highest predictions for all receptors can also be generated.

Some models also allow files to be generated that record the number of exceedances of a user-specified threshold value at each receptor. This function allows, for example, the production of graphs or tables showing the percentage of time that model results exceed the evaluation criteria.

AUSPLUME also provides for the generation of a binary file containing all results for all receptors, and in the current version (5.4) of AUSPLUME these data can be processed from within the GUI using the 'statistics utility' to produce percentile data files for the highest, second-highest, and 99.9, to the 90th percentile value.

ISCST3 allows the generation of a 'POSTFILE', which contains all results for all receptors. The postfile can be read by post-processing subroutines such as 'Percent View' by Lakes Environmental (free to download from www.lakes-environmental.com), and used to generate statistical data for each receptor.

Recommendation 53

For the purpose of comparing modelling results to an evaluation criterion:

a) run the model for the minimum period of one full year of meteorological data where possible (i.e. 8760 hours)

b) identify the receptor(s) that are most highly impacted and those that are most sensitive

c) for the receptor(s), report the 99.9 percentile value of the predicted ground-level concentration as the maximum ground-level concentration likely to occur.

Provide an indication of the representativeness of the 99.9 percentile value ground-level concentration by also presenting a number of other percentile values (e.g. maximum, 99.5th and 99th percentile values).

Use the frequency of exceedances to indicate the frequency of 'pollution events' that exceed the evaluation criterion being used.

Reporting the 99.9% predicted value is not simply a case of listing the highest 100 predictions over all receptors and then taking the ninth value on that list. This is a common mistake. The 99.9% value reported must be with reference to a specific receptor, which must be located at the point of highest impact. To ensure that the area of highest impact is identified, it may be helpful to plot contours of both the maximum and 99.9% values. An alternative is to list the ninth-highest value for every receptor and report the highest value identified.

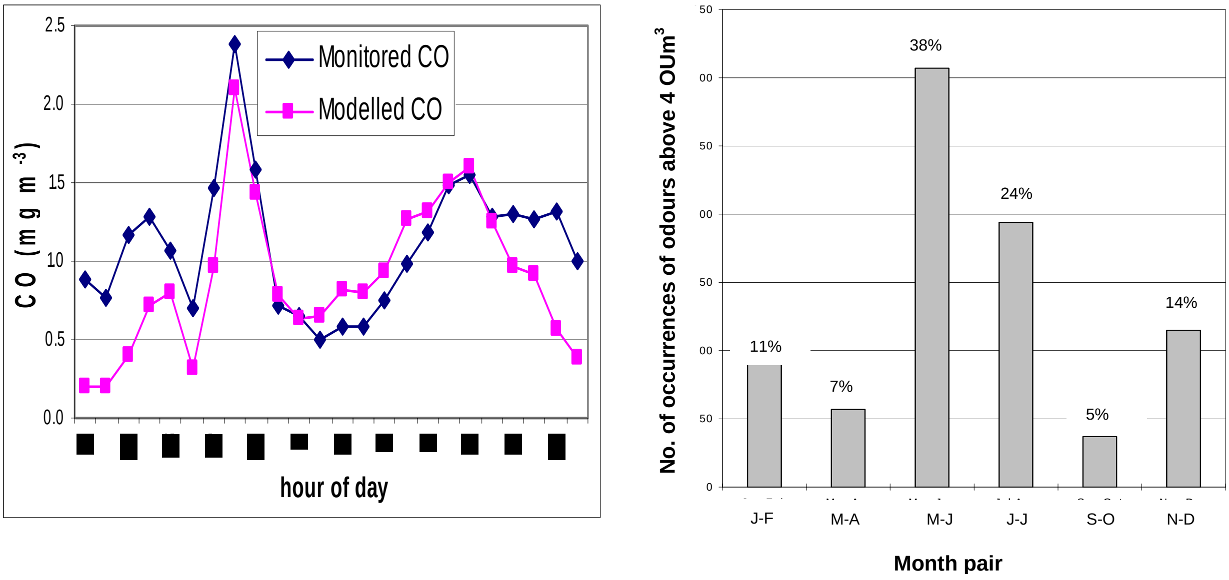
6.1.2 Tabulated results

An example of tabulated results from AUSPLUME for the highest ground-level concentration at each receptor is shown in Table 6.1. ISCST3 and CALPUFF files show a similar format. This table shows that the highest ground-level concentration (in these grid locations) is located 10 m East, 70 m North, was 0.809 (concentration units) and occurred at 8 pm on 18 May 1997. Such data can be imported into spreadsheets like Excel or Lotus and sorted to analyse for seasonal or daily trends (Figure 6.1).

Table 6.1: Example of tabulated results in AUSPLUME

Highest recordings for each receptor (in concentration units)				
Averaging time = 1 hour				
X (km):	0.000		0.010	
Y (km)				
0.100	2.79E-01	24,27/02/97	2.93E-01	24,27/02/97
0.090	3.57E-01	24,27/02/97	3.71E-01	24,27/02/97
0.080	4.64E-01	20,18/05/97	4.79E-01	24,27/02/97
0.070	7.64E-01	20,18/05/97	8.09E-01	20,18/05/97

Figure 6.1: Examples of analysis for daily and seasonal trends



6.1.3 Graphical results

Models can generate data files for importing into a graphics programme. ISCST3, AUSPLUME, and CALPUFF (via the post-processing programme CALPOST) all produce data files summarising the results in an ‘x, y, z’ three-column ASCII format (x co-ordinate, y co-ordinate, concentration) suitable for importing into SURFER for graphical analysis. SURFER is the most commonly used plotting programme with dispersion models. AUSPLUME links directly to SURFER for graphical utilities within the AUSPLUME GUI.

Spreadsheets such as EXCEL are also used for graphing one-dimensional data from screening analyses, such as that shown in Table 6.1.

Following are some suggestions for preparing graphs in SURFER from modelling simulations.

Set the number of points in the SURFER grid to be the same as your number of receptors (section 4.2.2).

Overlay the graphed concentration contours with a base map and terrain map (if appropriate) to allow people viewing the graphs to understand perspective, scale, and context of the results (e.g. ‘Where’s my house in relation to this?’). If you do this, make sure that your scale is the same on both the contour map and the base map, and if possible overlay the two maps onto the same axes using the ‘Overlay Maps’ function.

Remember that SURFER is simply a mathematical interpolation programme that draws contours of best fit between your data points. If your number of data points is low, the interpolation may look poor. Pockets of concentric circles often indicate an anomalous data point which is out of place compared to neighbouring receptors, and the data file used to create the graph should be checked.

If you have multiple source groups in your model, then AUSPLUME lists the results for each group one after the other in the same plot data file. These must be divided into individual plot files using a text processor before importing into SURFER.

SURFER will allow you to calculate the area of a receptor grid that is impacted by concentrations above a user-defined level. This can be a useful tool if you want to explore the extent of impact as well as the magnitude.

‘Percent View’ by Lakes Environmental (free to download from www.lakes-environmental.com) can be used to generate percentile plots (up to 99.0%) for whole ISCST3 grids, (Figure 6-2 and Figure 6-3).

Results of the top 100 (say) predictions can also be used to generate detailed percentile statistics at any given receptor by making the grid so small that it only includes one receptor at the location you’re interested in. The results table then shows the top 100 results for that receptor, which can be used to calculate the 99.9, 99.0, 98.0, 95.0 percentiles, etc, and graphed (Figure 6-4).

Similar statistical post-processing options to those in ISCST3 and AUSPLUME are available in CALPUFF’s post-processing program CALPOST.

Figure 6.2: Example of a contour map overlaid with a base map

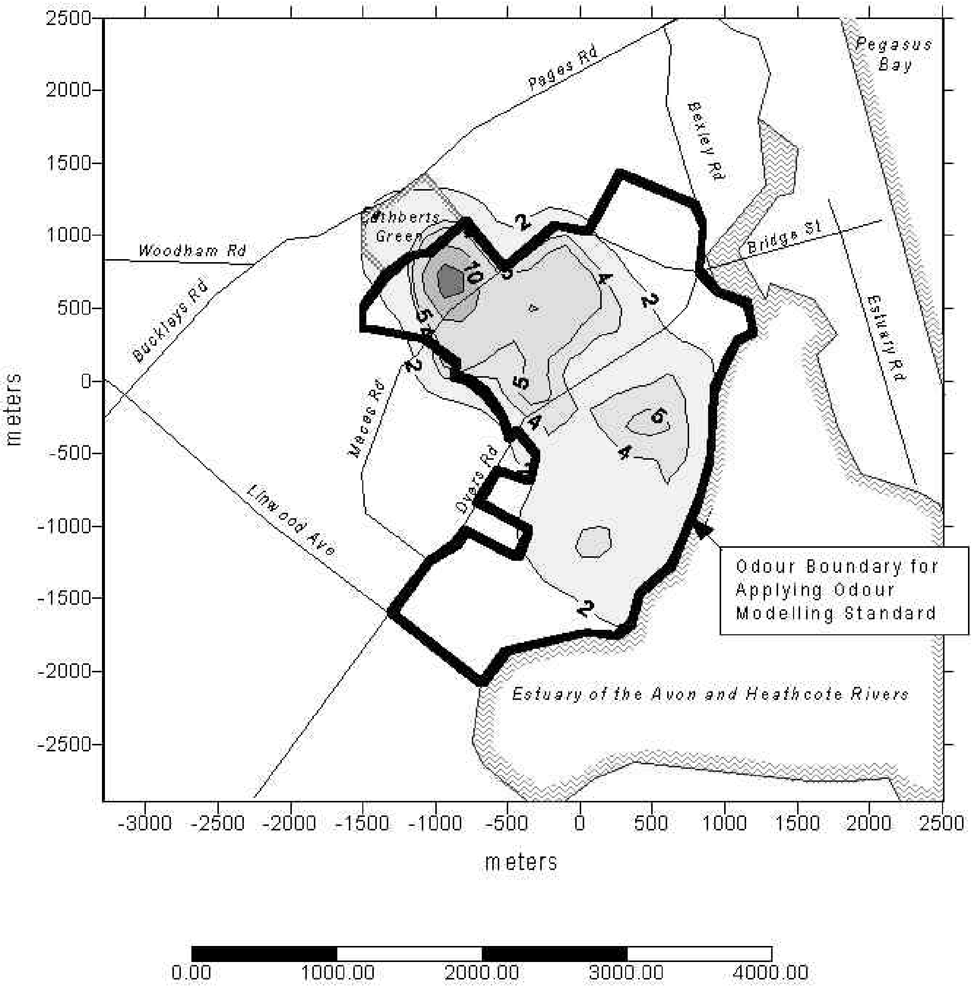
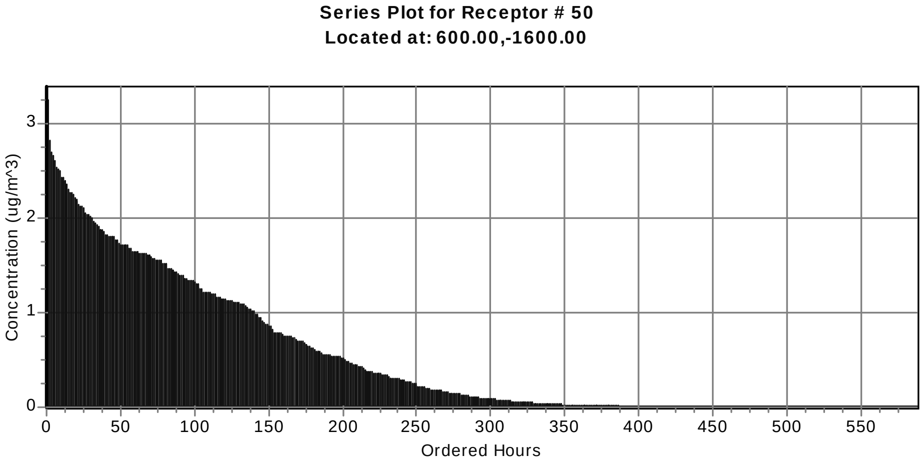
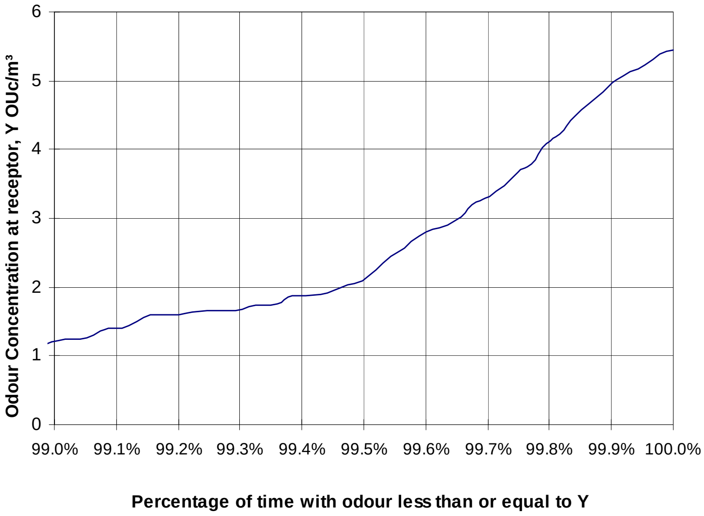


Figure 6.3: Series plot for a single receptor generated by Percent View



Source: Lakes Environmental.

Figure 6.4: Example of percentage occurrence analysis at a single receptor



Recommendation 54

Present modelling results graphically whenever it is helpful and appropriate.

Use sufficient labelling and include legends to allow people without expert training or experience in dispersion modelling to understand the data.

If presenting contour plots:

a) indicate the location of sources, site property boundary and potentially sensitive receptors
b) keep the number of concentration contours to the minimum necessary for conveying the information
c) include the relevant evaluation criteria
d) paste the contours over a map or photograph of the impacted area
e) calculate the area of a receptor grid that is impacted by concentrations above the evaluation criteria. This is a useful tool if you want to explore the extent of impact as well as the magnitude.

Present a percentage occurrence analysis for sensitive receptors.

Present graphs showing the daily and seasonal variation of the ground-level concentrations caused by the contaminants discharged from the source.

Include the plot file data as an electronic appendix to the report.

6.2 Accounting for and reporting of model error and uncertainty

One of the most common criticisms of dispersion modelling is, "It's not at all accurate – it's only a model". To avoid such criticisms it is important to follow some simple principals, as listed in the recommendation box below.

Recommendation 55

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

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

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

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

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

The total uncertainty contained in the model results is the cumulative effect of these sources. It is useful here to distinguish between 'reducible' and inherent uncertainty. Reducible uncertainty includes the accuracy of the input data (sections 6.2.1 and 6.2.4), and the way in which the model is run (sections 4 and 6.2.3). The inherent uncertainty is the fundamental limitations in the way a model works. This is beyond the control of the model user but is an issue they must be aware of (section 6.2.2).

6.2.1 Input data uncertainty

Any model is only as good as the input data. But of course the question is always: how good does it need to be?

There are three sets of data needed for dispersion modelling:

(a) source, or emissions characteristics,

(b) meteorological data, and

(c) terrain and local features data.

a Source characteristics

The critical factor is to know the rate of emissions, in mass units (grams per second or kilograms per hour or tonnes per day), of the contaminant of interest. This needs to be known for each time period of the model run, usually hourly for a year. Only in very special cases is this constant and known accurately. There are several possible approaches.

- The most common method, which is usually easy to achieve and justify, is to use the maximum emission rate. This occurs when an appliance is operating at its upper limit (e.g. a coal boiler consuming the maximum amount of fuel for which it is designed). If the emissions are measured by an ‘approved’ method, this is ideal. Guidance on emissions monitoring methods can be found in the Ministry’s *Compliance Monitoring and Emissions Testing of Discharges to Air* (MfE, 1998). If actual emissions measurements are not available, then either a manufacturer’s design specification or an emission factor (refer section 4.1.2) can be used.
- Another method, applicable in many circumstances, is to use a percentile discharge rate – either 99.9%, 99.5% or even 95%. This is common in processes that can have occasional upset conditions, such as a wastewater plant malfunctioning. Using the upset rate can bias model results severely, leading to predicted concentrations that might be far higher than are ever likely to occur because the particular combination of discharge and meteorology leading to these concentrations might be very rare. This should be investigated and the use of a percentile discharge rate should be clearly justified.
- A method occasionally used is to measure rates that vary by time of day, day of week, or season. Some processes do not discharge all the time, and modelling that takes account of this is more realistic.
- For processes where there is a known hourly discharge rate, in theory these can be directly input into the model, along with the concurrent meteorological information, to produce a very accurate assessment. In practice this is almost never done. This level of accuracy in emissions rates is usually not warranted, as the uncertainties in other factors (meteorology, terrain, model performance) take over.

The overriding feature is that peak modelled ground-level concentrations will be directly related to the emission rate, so it is important:

- to use a rate that is sufficiently large to cover the worst-case discharge of concern
- that the period the maximum emission lasts for matches the averaging period of the relevant evaluation criteria.

Recommendation 56

Clearly state the value and the origin of the source characteristics data that have been put into the model.

Include a copy of the model input file as an (electronic) appendix to the report.

Justify your choice of a particular value of a parameter, or run the model with a range of possible input values.

Preferentially use measured source characteristic values over estimated rates or emission factors.

If using calculated source characteristic values, clearly state the method used to calculate the value. Provide detailed calculations in an appendix to the main report and explain potential uncertainty with the values.

Pay particular attention to emission rate data by:

a) using a rate that is sufficiently large to cover the worst-case discharge of concern
b) ensuring the period the emission lasts for matches the averaging period of the relevant assessment criteria.

Provide a sensitivity analysis of model results to variation in source characteristics. This can be done by running the model with the two extreme values of a particular characteristic (e.g. low and high efflux velocities).

Facilitate an independent review of the source data and avoid requests for further information by reporting all sources of data and assumptions made.

b Meteorological data

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

The ideal is to have at least one year of data, with at least hourly resolution, at the site of interest (usually within a few hundred metres). The minimum measurement requirements are for wind speed and direction, but some method of estimating stability and mixing height is also required as an input for steady-state modelling. A full description of the meteorological detail is contained in section 5.

Often there are no suitable meteorological data at all. In this case, a ‘screening’ modelling study using a theoretical meteorological data set can be done. This will uncover the worst-case situation, and show the highest concentration that might occur. However, it gives no information on the frequency or location of the peak concentration, nor on the percentile statistics. When the predicted maximum ground-level concentration is well within the evaluation criteria, the use of a screening model may be sufficient. However, where the predicted ground-level concentration is higher than the evaluation criteria, a more thorough modelling study may be required and more accurate input data (including meteorological and emissions data) will be needed.

For each step in improving the meteorological data, the accuracy and reliability (and 'modelling believability') of modelling results improves. Possible improvements include:

- a simple mast with basic monitoring equipment in the general vicinity
- a simple mast at the site
- a well instrumented mast
- an array of masts
- full vertical sounding data
- model-generated data (using mast and/or sounding data)
- periods longer than one year
- previously used data sets (with accuracy confirmed in previous studies).

When the site is not uniform, further problems can occur. This frequently happens in New Zealand. For instance, the plume is influenced by meteorological conditions that are not the same as those at the site. Winds at plume height may be different from those at the surface, sometimes substantially so. There are also more subtle problems with conditions changing during the modelling period. Some models can handle this (especially puff models), but additional detail in the input data is required.

The required accuracy of modelling results and input data is guided by national guidance in this document and the *Guide to Assessing Discharges to Air* (currently under development), requirements in regional plans, recommendations from council staff and reviewers, and legal/council precedents. A key component of this system is often the use of independent reviewers of modelling, particularly in cases where there is an indication that some contaminant concentration is close to, or exceeding, the evaluation criteria. To assist councils, reviewers and modellers, some key principals should be followed when deciding on and reporting information about the level of detail in the meteorological input data. These are given in the recommendation box below.

Recommendation 57

Clearly state the origin of the meteorological data that have been put into the model.

Minimise the meteorological input data uncertainty by following (as far as practicable) the recommendations made in this document in section 5.

Facilitate an independent review of the meteorological data by reporting all sources of data, assumptions made and any guideline recommendations not followed.

Assess the sensitivity of the model's prediction of the magnitude of the maximum ground-level concentration to meteorological input data. Do this by running the model with data from a number of years, or data from a site with similar climate and meteorology. A comparison with results obtained using screening data can also be useful.

Include a copy of the meteorological data file(s) used as an (electronic) appendix to the report.

c Terrain and other local features

As discussed in section 4.3.4, dispersion modelling requires information about the terrain features surrounding the site that affect dispersion and plume behaviour. These include:

- terrain descriptions
- the location and size of hills
- building features
- surface features such as roughness length
- heat flux (for some models).

Determining the required accuracy for terrain and other local features is quite subjective. In many cases the decision is determined by what is available rather than what is required. It is also very dependent on the application; for instance, for mildly buoyant sources with low stacks, the building downwash issue can be critical, and building dimensions and orientations will determine the accuracy of the model prediction. At the other extreme, for hot, buoyant sources, discharged through tall stacks with final plume heights above 100 m, the building dimensions are irrelevant.

Similar arguments exist for each of the other parameters, and so the effect of terrain information on the accuracy of the model will vary between different applications.

Recommendation 58

Clearly state the origin of the terrain data that have been put into the model.

Justify your choice of a particular value of a parameter, or run the model with a range of possible input values.

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

6.2.2 Model performance

After input data uncertainty, the fundamental limitation for dispersion model accuracy is the way the model works. This includes the structure, physics and chemistry, and the way these are all parameterised and computed. There is considerable debate over this, as can be attested by anyone who has attended a technical meeting of model authors, and watched them defend their model's features!

In theory, it should be possible to evaluate any model's performance by a formalised evaluation scheme, whereby it is compared with actual monitoring results (with all other things being equal – emissions rates, meteorology and terrain). Indeed this is done to compare different models. However, in practice this is a complex and expensive process, and virtually impossible for all circumstances. The issues associated with evaluating model performance are outlined in detail by Hanna (1988) and Weil et al. (1992). More recently, model validation has been addressed by the initiative on the Harmonisation within Atmospheric Dispersion for Regulatory Purposes (http://www.harmo.org/). One of the outcomes of this initiative has been to produce the so-called *'Model Validation Kit'*.[1] This kit is a collection of three experimental data sets accompanied by software for model evaluation.

Most of the commonly used models have undergone some form of validation of their performance. It is recommended that model users should familiarise themselves with the relevant literature before using and presenting results from a particular model. Table 6.2 contains examples of the validation studies that have been undertaken.

Table 6.2: Model validation studies

Model	Authors (year)
ISCST3	Hall et al (2002)
ISCST3	Riswadkar and Kumar (1994)
TAPM	Luhar and Hurley (2003)
TAPM	Luhar and Hurley (2002)
CALPUFF	Strimaitis and Chang (1998)
CALPUFF	Tolga (2003)

One of the most commonly applied models in New Zealand, AUSPLUME, does not have an extensive series of formalised evaluations, instead relying on its similarity to standard Gaussian-plume models, such as ISCST3, which have been validated. One of the validation studies of AUSPLUME that has been completed (Bluett, 1998) shows that the model's performance in New Zealand is generally within a factor of two and similar to that observed in overseas studies.

A further complication exists in New Zealand, where many cases have complex terrain features. Complex terrain is handled poorly by Gaussian-plume models, and where it is an issue advanced models should be used. In theory, advanced models should give very accurate results provided adequate input data are available.

It is typically accepted that accompanied by good input data, dispersion modelling may be used to predict concentrations within a factor of two.

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[1] http://www.dmu.dk/atmosphericenvironment/Harmoni/M_V_KIT.htm.

Recommendation 59

The ‘factor of two’ performance guideline is probably still applicable to Gaussian-plume models. In the interim or until the model is validated, it is probably a safe estimate of likely model accuracy.

If the model shows that the peak concentration is less than half the evaluation criteria, then it can be accepted with a good degree of confidence that the criteria will not be exceeded.

A result showing, say, just 20% under the evaluation criteria is not enough evidence to show that the relevant criteria will not be exceeded. Further evidence, such as conservative inputs or validation of model results against monitoring data, should be used to demonstrate the robustness of results that are relatively close to the guideline (or national environmental standard) value.

Greater confidence can be placed in the results of well-validated and well-executed plume and puff models that have accurate input data.

Until greater general experience is gained or some further formal validation studies are completed, it is not possible to say how much more confidence can be given to well-executed plume and puff models.

Model performance should be regarded as better in simple compared to complex situations (e.g. flat compared to hilly terrain).

6.2.3 Misapplication of models

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

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

There are no specific recommendations to avoid these problems, except to approach all modelling results with caution and to seek further information where anything is not clear. However, provided modellers have reasonable experience and clearly document the model development and analysis of results, any misapplication of models should be avoided or picked up by the council assessor. Misapplication can also be avoided by discussing modelling options with the council assessment officer before commencing the modelling exercise and submitting the assessment of environmental effects.

Recommendation 60

Avoid misapplication of models by clearly documenting the development of the model and the analysis of its results.

6.2.4 Minimising errors

Despite the limitations discussed above, there are several practical steps that can be taken to minimise uncertainty in modelling results.

a Check, check and check

It is remarkably easy to get one or more inputs wrong. Figures get transposed, formatting is not right, there is poor quality control on input files, revised output gets overlaid on old outputs, plotting results on maps are in the wrong place – even things like using northern hemisphere co-ordinates because they are the default. Many of these errors can propagate into the final results. There is no substitute for checking. As a general guide, it is worthwhile spending almost as much time checking all the inputs and data used as setting up and running the model. Methods that can be used to check input files and output data are provided in section 6.3.

b Sensitivity analysis

Another more formalised way to assess model result uncertainty is to conduct a few extra runs with slightly changed parameters. What if we make the stack slightly higher? What if we restrict minimum mixing heights to 50 m instead of 30 m? What if we ‘move’ the source 100 m further out? What if we change the roughness length from 0.5 m to 1 m? Each of these actions should have a broadly predictable effect on the results If this isn’t as expected, something may be wrong. This analysis determines which are the important parameters; that is, those to which the model results are most sensitive. These are the parameters that need to be known with the most certainty.

c Percentiles

Model results are increasingly presented in terms of percentile exceedances, rather than absolute maximum results. This makes the results more robust, and probably more realistic for what people want out of the modelling assessment. Ground-level concentrations at any particular receptor may be highly skewed. The absolute worst hour may have a concentration twice that of the second-worst hour, and 10 times that of the ninth-highest. However, the ninth-highest may only be fractionally above the tenth-highest. This means the modelling result which is taken out and used (often just a single figure) is greatly sensitive to modelling uncertainty when it is the peak, but much less so when it is the 99.9 percentile.

Recommendation 61

Use an independent person review (and perhaps cross-check) all of the model inputs and outputs. It is not sufficient for the reviewer to consider the final hard copy of the report.

Check model results for 'realism' (e.g. diurnal or seasonal variation).

Where appropriate, perform a sensitivity analysis by conducting extra model runs with parameters changed to reflect the extremes of any particular parameter (e.g. high and low efflux velocities).

Present results for the maximum concentration and a range of percentile statistics to provide an indication of the sensitivity of the maximum ground-level concentration to the model inputs.

6.3 Analysis and interpretation of model results

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

Are the highest concentrations in the right location?

- Expect peak concentrations very near the source for low-level emissions.
- Expect peaks further downwind of tall stacks.
- Expect peaks on terrain features as plumes impinge on them (although these may not be realistic in a Gaussian-plume model if the hill is too distant).

Are the highest concentrations consistent with the meteorological conditions?

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

Do the highest concentrations coincide with the maximum emissions?

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

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

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

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

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

These considerations will help the interpretation and provide information that can be used to validate the model results. They will also help to determine the relationships between pollution levels, meteorology and emissions. Finally, if required, the above considerations will enable predictions of what would happen under alternative scenarios. Any predictions should be tested through further model runs, which might incorporate changes in or redesign of the emitters; for instance:

- restriction of operation times
- changes in stack height, stack location or fuel type.

Most emission options will probably have been specified in advance, but the modelling may be used to indicate other options. These tests are in addition to the sensitivity studies described above.

Recommendation 62

To provide a full interpretation of the results provided by any dispersion model:

a) carry out an analysis of the dispersion model results, ensuring that periods of extreme concentrations are consistent with the meteorological conditions, geographical situations, source configuration and emission rates
b) examine the relationships between concentrations, meteorology and emissions
c) compare the dispersion and meteorological model results with observations (if available).

6.4 Accounting for background concentrations

While there is usually a case for assessing the effects of a particular discharge, people are more interested in the overall end result – the cumulative effect. The Resource Management Act 1991 also requires this, and it is spelt out in most regional plans.

This means that modelling results must be added to current background concentrations discharged by other sources. It sounds simple, but there are many issues to deal with, including:

- If background data concentrations are available, how should they be used?

- What if there are no background data?
- Do maximum predicted and monitored concentrations occur at the same time of the day and under the same meteorological conditions?
- Should the concentrations just be added?
- Should we use peak values or average values, or something else?

More detailed guidance on dealing with background concentrations will be provided in the upcoming *Good Practice Guide for Assessing Discharges to Air*.

Recommendation 63

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

6.4.1 When local air quality data are available

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

- the National Air Quality Database (http://aqdb.niwa.cri.nz/)
- the Ministry for the Environment's Global Environmental Monitoring programme (Auckland & Christchurch only)
- the Ministry for the Environment's Air Indicators web pages (http://www.environment.govt.nz/indicators/air/)
- regional, district or city council state-of-the-environment reports
- regional, district or city council monitoring programmes
- reports on specific monitoring programmes
- research data (universities and Crown Research Institutes)
- published papers
- consultants' reports (on consent applications)
- industry monitoring programmes
- airshed modelling.

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

Recommendation 64

When available, use locally recorded air quality data to assess background levels.

The use of background data for cumulative effects assessments should be accompanied by a discussion of its applicability for the intended purpose.

If there is any doubt as to the validity of the information, it should not be used without specific justification.

Meteorological data from the monitoring site should also be examined when assessing the background monitoring results.

6.4.2 When local air quality data are not available

In most cases, an assessment of cumulative effects is required, so background concentrations need to be estimated. Options for estimating background concentrations are discussed below.

a Model other sources

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

b Compare the location with somewhere similar

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

c Make a worst-case assumption

In the absence of any of the above it might be necessary to simply 'guess' the existing air quality. The safest guess is to assume a concentration that is at the upper end of what might be feasible, based on what is monitored in, say, Auckland or Christchurch. As an example, it is almost inconceivable that summer background PM_{10} concentrations in a small town would be greater than those found in the middle of Auckland, so it is reasonably safe to use the monitored values from Auckland. However, the fact that this approach is potentially overly conservative should be taken into account in the assessment.

d Start a new monitoring programme

If all else fails, or if the issue is likely to be of significant importance, start a new monitoring programme as soon as possible. This need not be expensive, as useful information can be gained from relatively short-term surveys, or from passive monitoring. Comprehensive guidance on setting up ambient air quality monitoring stations is provided by the Ministry for the Environment in the *Guide to Air Quality Monitoring and Data Management* (Ministry for the Environment, 2000b).

Recommendation 65

When locally recorded air quality data are not available, one or more of the following methods should be used to estimate background concentrations:

a) Model other sources to provide an estimate of background concentrations

b) Use data from a similar location affected by similar discharges and meteorology

c) Make a worst-case assumption of background concentrations

d) Start a new monitoring programme to accurately determine background concentrations.

6.4.3 How to incorporate background data

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

a Spatial co-incidence problems

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

b Time co-incidence problems

Both the modelled and the background concentrations vary with time of day. In most cases the peak due to a point source emission does not occur at the same time as the background peak (which in many parts of New Zealand occurs during rush-hour traffic times or where wintertime domestic burning is carried out, during inversion layers that form over night). High background concentrations therefore almost always occur in calm to light wind conditions, when plumes from point sources may not reach the ground. On the other hand, point source peaks usually occur in:

(a) highly unstable daytime conditions

(b) in stable, light-wind night-time conditions or

(c) during the transition from night to morning, when fumigation may occur.

c Peak vs average

Should modelled peaks be added to measured peaks? Or averages to averages? Or peaks to averages? Each can give very different results. The most sensible approach is to add a peak (or 99.9 percentile) modelled result to an average background, since it is highly unlikely that the peaks in the two cases will ever be co-incident. However, if the peak background concentrations do occur under the same conditions as the peak concentrations from the discharge then the two peaks should be added together.

A study on how to add peak predicted concentrations to background values was recently undertaken by the UK Environment Agency (Environment Agency, 2000). The study concluded that simply adding peak model concentrations to background concentrations can result in severe overestimation of the source contribution, and that a more realistic method is to add twice the annual mean background concentration to the peak (or 99.9th percentile) modelled concentration. This method has not been reviewed or trialled in New Zealand, and it is not possible to comment on its relevance to the New Zealand situation.

Recommendation 66

When assessing the cumulative effects, use available background concentrations and account for the:

a) spatial co-incidence
b) time co-incidence
c) peak verses average concentrations
d) issues that may exist between the modelled and monitored (or estimated) background concentrations.

6.5 Assessment of effects

The final part in the process of deciding whether the model uncertainty is acceptable is to use the modelling result to assess some effect of the contaminant on people or the environment. Even when a lot is known about the effects, there are large uncertainties in the actual individual effect. Formaldehyde is a good example: some people are sensitive to quite low values, whereas others can easily tolerate concentrations 10 to 100 times higher. Which value should be chosen?

Recommendation 67

Before undertaking modelling and preparing an assessment of effects, consult the relevant environmental authority and check out the *Good Practice Guide for Assessing Discharges to Air* (currently under development by the Ministry) to determine:

a) the contaminants of greatest concern
b) the potential adverse effects that need to be assessed
c) the sensitivity of the receiving environment
d) the assessment criteria that will be used to assess the modelling results.

6.5.1 Evaluation criteria

There are a number of ways to assess the environmental and health effects of discharges to air once modelling results are available. The first step is evaluation against the national environmental standards. More information on how to do this will be included in the *Good Practice Guide for Assessing Discharges to Air* (currently under development by the Ministry). This new guide will cover:

- information required to undertake an assessment
- guidance on the level of assessment required depending on the scale and significance of the discharge
- guidance on when modelling is required
- interpretation of results against national environmental standards
- recommended evaluation criteria for pollutants not covered in the national environmental standards
- guidance on when a full health risk assessment is required.

6.6 Unresolved issues

Despite the vast amount of research that has been conducted on dispersion modelling and the fact that it is used hundreds of times a day all over the world, there are several issues that remain essentially unresolved. These include issues relating to missing data, calms, extreme weather, trends and synergistic effects.

6.6.1 Missing data

There are often missing data periods, in both emissions and meteorological data sets. Since most models will not tolerate missing data, various techniques are used to fill these holes for the purpose of getting the model to run at all. What if a critical period is missing? Say the peak emission rate, or a particularly awkward period of weather. When this is noticed, it can be accounted for in some way, although often it might not even be noticed.

Recommendation 68

Carefully review the model and all of the input data for potential occurrences of missing data.

This is the modelling ‘reality check’, and its value should not be underestimated.

6.6.2 Calms

When the wind speed drops below about 0.5 m/s, the wind direction becomes undefined and unresolvable, and the plume can end up going anywhere, or simply pooling. Unfortunately, these are exactly the circumstances which can lead to the highest ground-level concentrations but which cause the steady-state Gaussian equations to fail completely (wind speed appears on the bottom line of the equations, and cannot be zero). To handle this, the model forces a minimum wind speed of typically 0.5 m/s (it used to be 1 m/s, and in future it may be less). Puff models are a little better, and in theory allow for very light winds. Under these conditions the puffs are able to diffuse and grow without being advected. Fortunately, for most locations and most discharges, this is a rare circumstance.

Recommendation 69

If calms are identified as a potential concern, a more complete risk analysis should be completed. This analysis should at least consider the frequency and the potential consequences of calm conditions.

6.6.3 Extreme weather

With a one-year meteorological data set it is entirely conceivable that the worst-case meteorological conditions are not identified, and thus not modelled. This is a common criticism of modelling, and in many cases needs to be addressed with a specific study on the representativeness of the period of data used. This is done by comparing some statistics of the modelling data set, such as average wind speed, with those from the closest long-term climate station in order to assess the representativeness of that particular period.

Recommendation 70

The potential effects of extreme weather on pollutant dispersion should be identified.

The meteorological data set that is being used should be checked to ensure it contains conditions that allow for the effects of extreme weather to be assessed.

6.6.4 Trends

Similar comparisons to those outlined above should be made for long-terms trends such as climate change, land-use patterns, buildings, or even drifts in emission rates that could potentially alter the modelling results.

Recommendation 71

Modelling studies should identify and address any long-term trends that may affect the conclusions of that particular study (e.g. increasing background levels over time).

6.6.5 Synergistic effects

It is well known that some contaminants have worse effects in the presence of others than they do on their own. This is a very specialised subject, and not addressed by any current dispersion models, nor most common guidelines.