Population Exposure to Air Pollution

Workshop: NIWA, Auckland. 2:00 to 5:30, Friday 10th November 2006.

Photo courtesy of NILU

This report is a consultation document for the specific purpose of providing the background information for the Population Exposure to Air Pollution workshop to be held at NIWA, Auckland on Friday 10th November 2006.

Population Exposure to Air Pollution

"Whosoever shall be found guilty of burning coal shall suffer the loss of his head." Edward I. Circa 1300

1. Introduction

This report is a consultation document intended for use as part of a forthcoming workshop and follow-up report providing guidance to councils on

1. How to Assess Population Exposure to Air Pollution

and

2. How to identify where screening and standard method air quality monitoring needs to be undertaken to comply with standards.

It is intended to be a brief introduction to the idea of exposure with some examples of exposure assessment and how similar techniques can be used as an aid to NES compliance. Some of the themes that it contains will be explored further in the workshop.

The National Environmental Standards (NES) came into effect on 1 September 2005. This legislation has large and far-reaching implications for resource managers, resource users and air quality scientists. The Air Quality standards apply in the open, everywhere where people may be exposed and require monitoring to be carried out where the standards are most likely to be breached. So, how do you assess where the standards are most likely to be breached and where to carry out monitoring?

"Protecting New Zealand's Clean Air" is a research programme currently being funded by The Foundation for Research Science and Technology (FRST). The Monitoring and Network Design research objective of this Programme, aims to improve PM_{10} monitoring networks and measurement systems in New Zealand. The outputs from the research will help resource managers and resource users meet the requirements of the NES as effectively as possible.

2. What is exposure?

Exposure to air pollution is a the integrated effect of the concentration of a pollutant in the air, the length of time a person is in contact with it, their activity level and their susceptibility to the particular pollutant. These factors combine to form a received dose of the pollutant. The effect the received dose has on the person, such as impaired health, is known as the response.

Some of the pollutants that are present in the air can enter the body by means other than inhalation – for example by absorption through the skin. Examples of pollutants where it is necessary to consider multiple pathway exposures are heavy metals (e.g., lead), or some organic compounds (e.g., polychlorinated biphenyls, dibenzodioxins and dibenzofurans). However, for the purposes of this discussion document we shall consider inhalation as the primary route into the body.

Estimates of exposure can be used to estimate the level of risk associated with a pollutant. This can be expressed as the risk to a population i.e. the number (and cost) of increased hospital admissions and days off work or as a risk to an individual person i.e. the increased likelihood of hospitalisation or lost work-days. They can also be used to identify “hot spots” where people are at highest risk and hence where management of air quality is of highest priority.

3. Pollutants of interest

There are many pollutants emitted to the atmosphere by a wide variety of processes. The maximum permitted ambient concentrations of five major pollutants is proscribed by law in New Zealand by the National Environmental Standards. These are shown in Table 1

Contaminant	Standard	Time Average	Allowable exceedences per year
Carbon monoxide (CO)	10 mg/m^3	8 hours	1
Nitrogen dioxide (NO_2)	200 µg/m^3	1 hour	9
Ozone (O_3)	150 µg/m^3	1 hour	0
Particles (PM_{10})	50 µg/m^3	24 hours	1
Sulphur dioxide (SO_2)	350 µg/m^3	1 hour	9
	570 µg/m^3	1 hour	0

Table 1. The National Environmental Standards

Carbon monoxide is a colourless, odourless gas formed as a result of incomplete combustion of carbon-containing fuels, including coal, wood, petrol and diesel. It is rapidly absorbed by the blood, reducing its oxygen carrying capacity. It is a relatively stable compound that takes part only slowly in atmospheric chemical reactions. It contributes indirectly to the greenhouse effect by depleting atmospheric levels of hydroxyl radicals and thus slowing the destruction of methane, which is a powerful greenhouse gas. The main sources which affect human health are smoking, car exhausts and heating / cooking appliances.

Nitrogen dioxide is produced by burning fossil fuels, e.g. road vehicles, power generation and industrial processes. Indoor sources include gas cookers, other unflued gas appliances and cigarette smoke.

Sulphur Dioxide is a colourless gas with a choking taste. It is produced by the burning of sulphur compounds which are a natural constituent of coal and oil. Major sources include: fossil fuel combustion, smelting, manufacture of sulphuric acid, conversion of wood pulp to paper and the incineration of refuse.

Ozone differs from the other pollutants in that it is not produced directly from emission sources, but is a 'secondary pollutant' created by photochemical reactions in the atmosphere involving oxides of nitrogen, hydrocarbons and other compounds in the presence of sunlight. Because road transport is a major source of the compounds involved in the reactions, it is an important contributor to ground level O_3 concentrations. The amount of O_3 in the air is governed mainly by the reaction between NO and O_3, to produce NO_2. Because roads provide an excess of NO from the traffic emissions, the reaction proceeds until most of the O_3 is depleted, and consequently, O_3 levels near to roads tend to be low. These reactions occur over a period of some hours, and elevated ozone concentrations are frequently found away from the original source of nitrogen oxides.

Particulates are dispersed into the air from combustion processes, industry and natural activities such as the weathering of soils. They are also produced as 'secondary particles' by chemical reactions in the air. They range in size from microscopic to visible – from a few nanometres to a few millimetres. Health effects result mostly from what are known as Respirable Particles. In New Zealand (as in most other countries) these are defined as particles with an aerodynamic diameter of 10 micrometres or less. This is generally abbreviated to PM_{10}. As a rule, particles produced from combustion and condensation tend to be 'fine' while those from mechanical processes tend to be 'coarse'.

4. Linking ambient concentrations to exposure.

Studies on the health effects of pollution fall into two basic types; epidemiological and toxicological. Toxicological studies, as the name suggests, examine the toxicity of substances under controlled conditions whereas epidemiological studies take a statistical approach to finding health effects in the population. These again are divided into two types, Cohort studies and Time-series mortality studies. Time-series studies look for statistical associations between pollution events and health indicators such as excess deaths, hospital admissions or work-days lost. Cohort studies on the other hand follow the lives of a group (or cohort) of people over a period of time. Time-series studies usually report short term exposure to relatively high concentrations of pollutants while cohort studies are more able to track long term exposure to lower levels of pollutants.

Although epidemiological studies have found a correlation between daily mortality and particle concentrations in outdoor air, personal monitoring studies have generally found very poor correlations between personal exposures and outdoor air concentrations. This lead to the suggestion of a “personal cloud,” an increased personal exposure beyond that calculated from a time-weighted average of indoor and outdoor concentrations [*Wallace*, 2000]. Most studies have been done on healthy people, who may be much more active and therefore create higher particle concentrations in their personal cloud than sick people. The personal cloud for a healthy person can be as high as 50 micrograms per cubic meter during the day when people are active, and may be a major reason for the poor correlations of personal exposure with outdoor air concentrations.

Epidemiological studies usually report findings in terms of increased risk to a population i.e. the number (and cost) of increased hospital admissions and days off work attributed to a given increase in ambient concentrations of pollutants. For example, Scoggins *et al.*, [2004b] report amongst other things, that a 1μg/m^3 increase in annual average NO_2 concentration in Auckland leads to a 1.8±0.3% increase in deaths from respiratory and circulatory illness in the population as a whole.

There have also been attempts to estimate individual exposure and hence risk. In New Zealand, the "Mrs Smith" project Scoggins *et al.*, [2004a] estimated the additional risk from pollution to a person as a result of living close to a roadway. In Europe the Urban Exposure project used GIS mapping software and inhalation dosimetry to estimate the cumulative dose of PM received by a person by "following" them through their daily routine [*Coulson et al.*, 2005]. Figure 1 shows a GIS output from the personal exposure module developed by the Urban Exposure project; it depicts the points on a subject's daily commute used to calculate the subject's intake (dose) of PM. Recently, models have been constructed that attempt to integrate meteorology, air pollution and exposure into a single framework [*Baklanov et al.*, 2006]

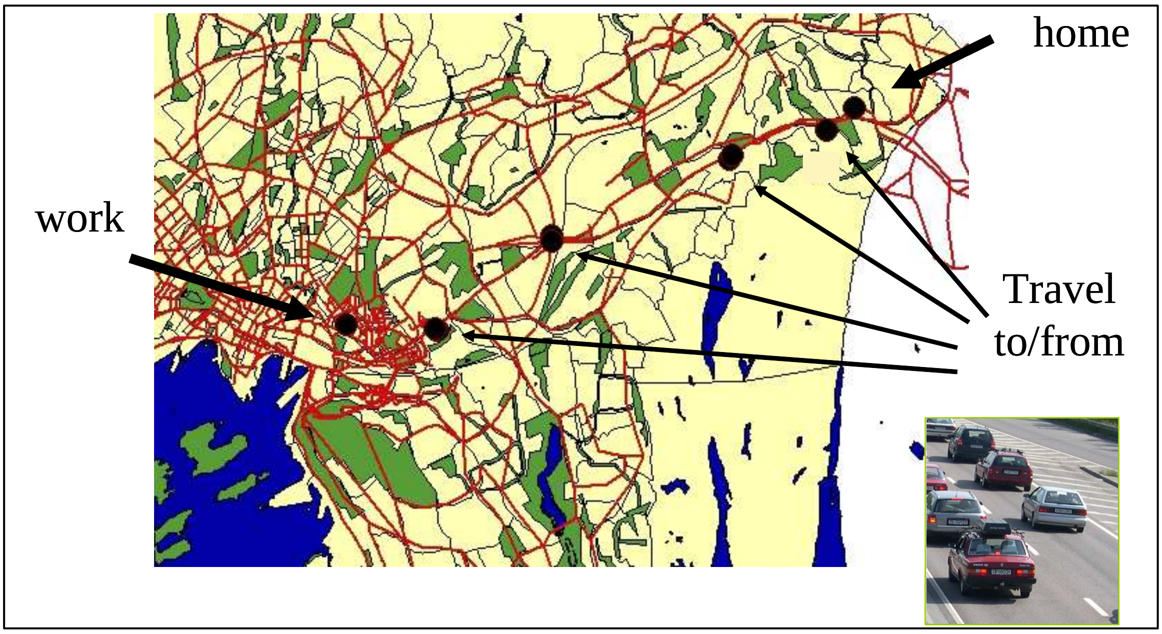

Figure 1. Example of a GIS image from the Urban Exposure module used to calculate a person's received dose of PM during their day.

How do measured ambient concentrations translate into received dose? There is no easy answer but inhalation dosimetry models [*Coulson et al.*, 2005] are able to estimate cumulative dosages in individuals as μg/kg body mass. The response to the received dose then depends on the toxicity of the pollutant (for example there is evidence that PM from traffic is more toxic than PM from other sources [*WHO*, 2004]) and the susceptibility of the individual person to the pollutant.

Toxicology, because of its simpler models and potential to tightly control exposures, provides an opportunity to determine the relative toxic potency of components of the PM mix, in contrast to epidemiology.

Such toxicology studies have highlighted the primary, combustion-derived particles having a high toxic potency. These are often rich in transition metals and organics, in addition to their relatively high surface area. By contrast, several other components of the PM mix are lower in toxic potency, e.g. ammonium salts, chlorides, sulphates, nitrates and windblown crustal dust such as silicate clays. Despite these differences among constituents, under laboratory conditions it is currently not possible to precisely quantify the contributions from different sources and different PM components to health effects from exposure to ambient PM [*WHO*, 2004].

4.1. Confounding factors

Even though associations can be found between ambient pollution levels and increased incidence of adverse health effects, care needs to be exercised when ascribing causal links. The effects that ambient air pollution can have on health can also be caused by a number of other factors such as extreme temperature (hot and cold), smoking, allergies, occupational exposure and indoor air pollution. Certain sectors of the population (the very young, the very old, those living in poor housing etc.) are also known to be at higher risk of the illnesses associated with ambient air pollution regardless of the actual cause.

The effects of these factors can mask the signal from ambient air pollution. For example, an outbreak of influenza would be expected to cause a similar set of symptoms and health effects as a pollution event. If the two happen simultaneously it can be difficult to disentangle which cause is responsible for which effects. The two events may well be additive in that those suffering from influenza may become more susceptible to the effects of pollution and hence a higher number of hospitalisations may occur than would happen from one event alone. These confounding factors need to be accounted for in any analysis of the health effects of ambient air pollution.

Different pollutants can be confounding factors for each other. For example, PM_{10} and NO_2 can cause similar respiratory conditions. This can lead to an element of double counting. To preclude double counting of adverse health effects related to air pollution usually only one pollutant is chosen to quantify health outcomes [*Lipfert and Wyzga*, 1995; *Lipfert and Wyzga*, 1997]. Particulate matter is usually considered the single pollutant; hence the health effects due to CO, NO_2, and SO_2 are not necessarily independent. There is considerable evidence, from numerous studies, that particulate effects dominate the total health effects, accounting for up to 85% of the total health costs [*Fisher et al.*, 2005]. Sarnat *et al.*, [2006] report that ambient concentrations of PM2.5 are stronger proxies of personal exposure than gasses such as NO_2 and Ozone.

4.2. Choice of indicators for New Zealand

Because of the interactions of different pollutants with each other and with other variables such as weather, it is usual to choose a single variable to act as an indicator for the health effects of the aggregate pollution mixture. As noted above, current research indicates that PM in general and $PM_{2.5}$ in particular are considered strong proxies of personal exposure. In New Zealand, $PM_{2.5}$ is not monitored on a regular basis and information concerning its distribution is scarce. PM_{10} has only been regularly monitored for a few years but data are more plentiful. Where PM measurements are not available, the health effects of NO_2 have been found to correlate with those from PM [*WHO*, 2006] so if measurements are available, NO_2 could also be used as an exposure proxy.

In urban Areas of New Zealand, PM_{10} is the major pollutant of concern for NES compliance. There are now monitoring programmes underway in many locations so it is not unreasonable to choose it as the indicator species for the health effects of pollution in general.

In areas where there are no or insufficient monitoring data, estimates of exposure may have to be made from other sources such as emissions inventories. Outside the major urban centres, it may also be difficult to derive any statistical relationships due to low population density and exposure estimates may have to be calculated using other quantities; for example, kilogrammes of pollutant emitted per person per year into a Census Area Unit (CAU).

In the absence of any pollution data at all, it is also possible to use other indicators as proxies for exposure. For example, Lipfert *et al.*, [2006] found that traffic density showed strong correlations with health effects in a cohort study in the US.

5. Why is Air Pollution Exposure Important in the Context of the NES?

What do the standards have to say about exposure?

> The NES (Clause 14) states that the standards apply at any place –
> a) that is in an airshed; and
> b) that is in the open air; and
> c) where people are likely to be exposed to the contaminant.

There is also a requirement for monitoring (regulation 15) where;

> If it is likely that [a standard] will be breached … the regional council must
> a) monitor the …contaminant; and
> b) conduct the monitoring –
> - in that part of the airshed where there are one or more people…

So, in terms of the NES, “exposure” is simply a concentration of a pollutant in a place where people will be exposed to it.

The NES don’t state how long the exposure should be but it is implicit in the averaging time used that the exposure should be of a similar order to the averaging time. For example, the NES for PM_{10} specifies that results should be reported as a 24 hour average. Therefore it is implicit that the measurements should be in places where people are likely to be exposed for 24hours. This will be principally (although not exclusively) in residential areas In practice, a test of reasonableness has been applied i.e. could it reasonably be expected that a person could (although not necessarily would) spend 24 hours at a given location? This test broadens the scope of the standard to include parks and other amenities. The averaging time stipulated in the NES for the other substances are all one hour or eight hours, which falls well within the reasonableness test at most locations.

Despite the simple definition of exposure, in terms of NES management exposure is also implicated in the definition of Gazetted Airsheds, identification of monitoring locations and planning and assessing the effectiveness of mitigation strategies

6. Some Exposure Assessments Undertaken in NZ

This section presents a brief summary of four studies that have addressed the issue of exposure to air pollution in New Zealand’s Cities. The examples presented in this document are not intended to represent a comprehensive list of work completed in NZ. They were selected for their relevance to the aims and objectives of the workshop.

6.1. Mrs Smith

The Mrs Smith study: Air pollution and health risks near roadways. Amanda Scoggins, Gavin Fisher, Shanju Xie, Jeff Bluett. NIWA Client Report: AKL2004-31. June 2004

The Mrs. Smith study was a NIWA report for the FRST aiming to quantify individual exposure arising from proximity to a given road. The exposure was calculated for a hypothetical “Mrs. Smith” living ion various parts of Auckland. The Mrs Smith risk evaluation model followed five steps: (1) defining where Mrs Smith lives; (2) estimating the roadside exposure at Mrs Smith house; (3) estimating background exposure for Mrs Smith; (4) estimating the baseline health risk for Mrs Smith; and (5) calculating the health risk for Mrs Smith due to the road itself versus other (background) exposures. The risk evaluation model was then used to estimate exposure in two scenarios, one close to a major road in central Auckland and one close to a road in a suburban area. In both scenarios the majority of Mrs Smith’s health risk was attributable to background exposures rather than because she lived 20m from a single road. For each pollutant a range of health effects were shown with the relevant health risk (above the baseline risk) attributable to either Mrs Smith’s road or background air pollution exposure.

The key results are that a person living near a road in a relatively 'low' air pollution area of Auckland (Glendene, Waitakere City), might experience a 20% greater risk from exposure to fine particulates than someone living outside of Auckland – and of this 13% is due to the roadway, and 7% due to the background in the area. Conversely, a person living in a 'high' air pollution area (Gillies Ave, Auckland City), might experience a 50% greater risk from exposure to fine particulates than someone living outside of Auckland – and of this 15% is due to the roadway, and 35% due to the background in the area.

6.2. HAPiNZ

Health and Air Pollution in New Zealand: Christchurch Pilot Study
G. Fisher, T. Kjellstrom, A. Woodward, S. Hales, I. Town, A. Sturman, S. Kingham, D. O'Dea, E. Wilton, C. O'Fallon, A. Scoggins, R. Shrestha, P. Zawar-Rewa, M. Epton, J. Pearce, J. Sturman, R. Spronken-Smith, J. Wilson, S. McLeod, R. Dawson, L. Tremblay, L. Brown, K. Trout, C. Eason, P. Donnelly. http://www.hapinz.org.nz/

A major multi-institutional study of the health effects of common pollutants from all major sources in the Christchurch region. This report is a pilot study which is intended to be extended to cover the whole of New Zealand. It covers health effects, economic impacts and policy options. It also contains a fairly substantial literature review of available research from both overseas and NZ.

The HAPiNZ study assessed exposure using a combination of emissions inventories, monitoring, GIS interpolation of monitoring results and high resolution modelling (using The Air Pollution Model TAPM).

Its key findings are that some 158 people over the age of 30 die each year in Christchurch from the effects of air pollution. The way these deaths break down by source is shown in Table 2. The economic costs of the health effects of air pollution are estimated to be $168 million per year of which 76% is attributable to domestic emissions from home heating.

Pollution Source		Domestic	Industrial	Vehicle	Total
Mortality		124	18	16	158

Table 2. Premature deaths in Christchurch due to air pollution, by source.

It is stressed that because of the particular seasonal distribution of pollutants in Christchurch that this pilot study should not be generalised to other places in New Zealand. Further work is required before the methods developed in this study can be applied elsewhere.

The HAPINZ study has now been extended to the whole of New Zealand but results are not available at the time of writing.

6.3. Scoggins *et al* (2004)

Spatial Analysis of Annual Air Pollution Exposure and Mortality. Scoggins A, Kjellstrom T, Fisher G, Connor J, Gimson N SCIENCE OF THE TOTAL ENVIRONMENT 321 (1-3): 71-85 APR 5 2004

A study to relate ambient air pollution levels to mortality in Auckland using a combination of urban airshed modelling and GIS. They used NO_2 as an indicator and found that the number of people estimated to die from non-external causes in Auckland is 268±42 per year and from respiratory and circulatory causes 203±34 per year. They also found that a 1µg/m^3 increase in annual average NO_2 concentration lead to a 1.3±0.3% increase in non-external cause mortality and a 1.8±0.3% increase in respiratory and circulatory cause mortality. NO_2 concentrations were calculated per CAU using CALGRID, which were then compared to mortality data filtered for confounding factors such as age, sex and socioeconomic grouping. The results were presented as GIS exposure mapsFisher et al (2002)

6.4. Fisher et al (2002)

Health effects due to motor vehicle air pollution in New Zealand. Report to the Ministry of Transport. G.W. Fisher, K. A. Rolfe, T. Kjellstrom, A. Woodward, S. Hales, A. P. Sturman, S. Kingham, J. Petersen, R. Shrestha, D. King.
http://www.transport.govt.nz/publications/niwa-report/index.php

A MoT commissioned study to investigate the effects of traffic pollution on the health of the New Zealand population. Based largely on methods developed by Kunzli *et al* [*Kunzli et al.*, 2000] it estimated exposure as the number of people over 30 exposed to annual average PM_{10} concentrations grouped into nine bands.

The key finding of this study was that approximately 400±160 people over the age of 30 die prematurely each year in New Zealand from the effects of vehicle pollution. This was compared to a figure of 970 people over the age of 30 dying prematurely each year in New Zealand from the effects of particulate pollution from all sources and 502 dying from road accidents. They also estimate that 64% of premature deaths occur in the greater Auckland region.

Their results are consistent with European studies, which show that mortality due to vehicle pollution is of the order of twice the road accident death toll.

6.5. Implications and lessons learned form these Studies

All four of these studies use some combination of monitoring and modelling; the modelling usually being used to calculate concentrations in the absence of monitoring data. They are generally quite large and complex studies but all present exposure in terms of risk; of health effects; of mortality and of financial cost. Most councils in NZ will not need such complex studies but will still need to know which members of their population are at highest risk from pollution exposure.

For managing the NES and designing monitoring networks at a local level a much simpler assessment of exposure may suffice. One based on the premise that the highest risk comes from the most people exposed to the highest concentrations will be enough to indicate, at least in the first instance, where monitoring is most needed.

7. Conducting an exposure assessment

There are various ways of conducting an exposure assessment ranging from simple screening techniques to advanced airshed modelling. The USEPA suggests the following approach [*EPA*, 1992] to decide which is relevant for a particular circumstance.

<u>Purpose</u>: Why is the study being conducted? What questions will the study address and how will the results be used?

<u>Scope</u>: Where does the study area begin and end? Will inferences be made on a national, regional, or local scale? Who or what is to be monitored? What chemicals and what media will be measured, and for which individuals, populations, or population segments will estimates of exposure and dose be developed?

<u>Level of Detail</u>: How accurate must the exposure or dose estimate be to achieve the purpose? How detailed must the assessment be to properly account for the biological link between exposure, dose, effect, and risk, if necessary? How is the depth of the assessment limited by resources (time and money), and what is the most effective use of those resources in terms of level of detail of the various parts of the assessment?

<u>Approach</u>: How will exposure or dose be measured or estimated, and are these methods appropriate given the biological links among exposure, dose, effect, and risk? How will populations be characterized? How will exposure concentrations be estimated? What is known about the environmental and biological fate of the substance? What are the important exposure pathways? What is known about expected concentrations, analytical methods, and detection limits? Are the presently available analytical methods capable of detecting the chemical of interest and can they achieve the level of quality needed in the assessment? How many samples are needed? When will the samples be collected? How frequently? How will the data be handled, analysed, and interpreted?

The complexity of any exposure assessment will depend on the answer to the questions above. For example, if the purpose is to identify or rank locations that require further investigation or to simply rule out locations that do not require monitoring, then a simple screening approach may be sufficient. In locations where further investigation is deemed necessary then monitoring, modelling or a combination of both may be required. In more complex cases, information on population, demographics and hospital admissions may also be included.

7.1. Screening study

A screening approach suggested for use in NZ is the Weighted Risk-Element Decision Matrix (WREDM) [*Bluett et al.*, 2005] to prioritise areas that are currently not monitored. Its scope can be broad, from local to national in scale but the level of detail necessary is not high. The use of the WREDM is a four-step process.

Step 1. Identify PM_{10} Monitoring Network Gaps

Having identified any gaps in a monitoring network a WREDM can be used to rank the gaps in order of importance so that resources can be distributed most effectively.

Step 2. Risk-Element Data

The WREDM uses four risk-elements for each area being considered. Each of the elements has been chosen to represent a risk factor that contributes to the total potential PM_{10} exposure. For simplicity the risk data used is limited to:

- Population, Emission and Land Area data
- A simple meteorological element (eg % calms in winter)

The specific risk-elements used are:

- Population - A measure of the number of people potentially affected by the pollutant
- Emission density - A measure of the amount of PM_{10} emitted for per area of land (g $PM_{10}/km^2/day$)
- The percentage of time with calm (wind speeds >2ms^{-1}) conditions - A measure of how poorly (or well) the pollutants are dispersed

Step 3. Scaling and Weighting the Risk-Elements

Each risk-element is scaled to provide a score out of 33 (a dimensionless value). This is selected so that the total of the three equally weighted elements totals 100. The scaled score provides an indication of relative risk for that particular element compared to the other areas under consideration. A high score indicates relatively high risk.

Step 4. Incorporating PM_{10} Monitoring Information

Step 4 uses historical monitoring data (if they exist) to develop a qualitative monitoring-factor. This monitoring-factor is used to scale the Total Risk-Element Score that determines the final priority. For example the values in Table 3 can be used as multipliers to determine a final score for the WREDM.

PM_{10} Monitoring Results	Monitoring-Factor to Apply to Total Risk-Element Score.
No monitoring results available	1
Monitoring results suggest PM_{10} exceedence unlikely	0.75
Monitoring results ambiguous or suggest PM_{10} exceedence possible	1.5
Monitoring results show PM_{10} Exceedences occur	2

Table 3. Qualitative Monitoring-Factor

In summary, the WRE-DM presented above should be used as a conceptual framework, which users can develop and improve upon to meet their individual needs and available data.

7.2. Risk evaluation

If the purpose of an exposure assessment is to assign a value to the risk imposed by the exposure, then a higher level of detail is required above the simple screening approach. For example the Mrs Smith Study [*Scoggins et al.*, 2004a] created a risk evaluation model using a combination of measurement and modelling.

To calculate a baseline background exposure, historical monitoring data were used to establish five “Exposure Airsheds” across Auckland, which were ranked from highest to lowest.

Exposure to traffic pollution was estimated using Vehicle Emissions Factors and traffic counts along with dispersion modelling to calculate concentrations at varying distance from the roadside.

These were combined with health statistics to infer the increase in risk attributable to roadside exposure.

The scope of the study was limited to estimating individual exposure at two locations in Auckland but the method is applicable on other scales and at other locations. This type of study can be used to assess in greater detail locations that have been identified as possible monitoring sites where little or no measurement data exist.

7.3. Complex Study – quantifying health and economic risk for a large population.

If the purpose of a study is to quantify risk for a large population such as a city or the whole country then the scope and the level of complexity become very large too. It becomes necessary to incorporate large data sets from several sources, pollution monitoring, health, economic and population statistics and so on. Complex models are required to manipulate all these data. It may even be necessary to create new models to give the desired outputs.

The HAPiNZ [*Fisher et al.*, 2005] study was an example of such a large complex study. It was a multi-institution, multi-year study with the aim of quantifying the risk to the population of adverse health effects and economic impacts from pollution. It also assessed the possible impacts of policy options.

8. Monitoring site location - How exposure estimates can help

Because current research indicates that there is no threshold value at which harm from particulates occurs, any concentrations above the natural background must be seen as potentially harmful. However, the NES simplifies this by being a pass/fail test. If a location is likely to fail the test (i.e. 24 hour average concentrations of PM_{10} are likely to be higher than 50µg/m^3 on more than one occasion per year) then the air quality in that location must be managed so that it passes the test as soon as possible. Monitoring is required as part of the management process to demonstrate compliance. If you know that a location is in breach of the NES then you must monitor. However, if no monitoring data are available prior to the introduction of the standards, how do you know where to monitor? Exposure estimates can be used to identify locations that may be in breach of the standard and to rank them in order of priority.

Using exposure estimates to locate sampling sites is an example of "Judgemental siting" that is using prior knowledge of source emissions and sensitive receptor locations, coupled with mechanisms for pollutant transport, to determine the location of measurement sites. Judgmental sampler locations may be determined by data from an existing monitoring network or by identifying the locations of pollutant sources and inferring pollutant transport from data analysis of emissions and wind measurements. Airshed modelling may assist in this process.

Other methods of choosing a site are *random*, *systematic*, or *heterogeneous* or based upon modelling techniques [See e.g. Watson *et al.*, 1997 and references therein]

Monitoring networks for criteria pollutants always use judgmental sampling strategies that consider where source emissions are in relation to populations and which way the wind blows. Indeed the legislation accompanying the NES demands the use of judgemental techniques.

Monitoring may be undertaken for a variety of reasons including;

1) the highest concentrations expected to occur in each airshed;

2) representative concentrations in areas of high population density;

3) the impact on ambient pollution levels of significant sources or source categories;

4) general background concentration levels;

5) the extent of regional pollutant transport among populated areas, and

6) welfare-related impacts in rural and remote areas (i.e., visibility impairment and effects on vegetation).

With regard to the NES, the first three are the most important leading to an estimate of where the most people are exposed to the highest concentrations of pollutants. Since resources are always limited, exposure assessments can be used as a way of prioritising those resources. By adding a quantification of risk, exposure estimates can then be used to rank locations where the most people are likely to come to the most harm in order of importance.

There are circumstances where judgements will have to be made. For example, is a small population being exposed to high concentrations of PM_{10} more or less at risk than a large population being exposed to lower concentrations? An exposure assessment may be able to quantify risk in terms of expected hospital admissions or lost productivity.

Without any other information, small scale test measurements or modelling may be required to determine if a breach of the standard is likely. Using screening techniques allows local authorities to rank potential sites in order of importance so that test measurements or modelling can be used most effectively. Screening is a short term measure even if it does include some monitoring. Its purpose is to identify the locations where long term or Standard monitoring is necessary for NES compliance.

9. Conclusions

This report is a consultation document intended for use as part of a forthcoming workshop and follow-up report providing guidance to councils on

1. How to Assess Population Exposure to Air Pollution

and

2. How to identify where screening and standard method air quality monitoring needs to be undertaken to comply with standards.

Exposure to air pollution is a combination of the concentration of a pollutant in the air, the length of time a person is exposed to it, their activity level and their susceptibility to the particular pollutant. These factors combine to form a received dose of the pollutant. The effect the received dose has on the person, such as impaired health, is known as the response.

From a combination of these factors, ambient concentrations leading to dose leading to response, it is possible to estimate the level of risk associated with a pollutant. This can be expressed as the risk to a population i.e. the number (and cost) of increased hospital admissions and days off work or as a risk to an individual person i.e. the increased likelihood of hospitalisation or lost work-days.

Studies in New Zealand have shown that a significant number of premature deaths and lost working days occur as a result of airborne pollution.

The NES were created to limit people's exposure to five harmful criteria pollutants. Under the NES, "exposure" is simply a concentration of a pollutant in a place where people will be exposed to it. Therefore an assessment of exposure is the starting point for any ambient air quality monitoring.

Methods of assessing exposure range from simple screening methods to complex combinations of measurement and modelling. A brief description of three different levels of complexity of exposure assessment is presented here. The first, the screening method (WREDM) is appropriate for most cases in New Zealand enabling the user to rank sites in order of priority for either monitoring or further investigation. The second level is appropriate for cases where locations have been deemed to require further investigation or the location is large or complex. The third level of complexity is used for assessing large or complex situations and is generally beyond the scope of NES implementation.

10. The Workshop

The exposure workshop will explore some of the ideas outlined in this document, giving an introduction to how exposure is measured and what exposure assessments have been done in New Zealand. This will be followed by presentations on how to conduct different types of exposure assessment and how to use the results to plan monitoring networks. Finally the afternoon will be rounded off with a panel discussion on how to use exposure assessments for NES compliance. A programme for the workshop will accompany this document.

After the workshop, a report will be issued, which will outline the contents of the workshop and the results of the discussions including recommendations for further work and any advice or guidance that may arise from them.

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