D7

VOLUME D: AIRSPACE

Health Impact Assessment

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GLOSSARY OF TERMS

AHR:	airways hyperresponsiveness.
Ambient Air Quality National Environment Protection Measure:	an Australian air quality standard.
cohort study:	a well defined group of subjects are followed over time to measure the relation between an exposure (e.g. pollution level) and an outcome (e.g. symptoms or lung function).
confounding:	where the presence of another risk factor confuses the true relationship between the factor under study and the outcome.
COPD:	chronic obstructive pulmonary disease.
mass median aerodynamic diameter:	a measure of particle size.
meta-analysis:	a systematic overview of related investigations which summarises the information they contain in one or more measures of association.
NH&MRC:	National Health and Medical Research Council.
NO_2:	nitrogen dioxide.
PEFR:	peak expiratory flow rate.
PM_{10}:	particulate matter with MMAD less than 10 µm.
ppm:	parts per million; a measure of gas concentration.
weighted average:	average of several estimates giving greater weight to the more certain estimates and lesser weight to the less certain estimates.
$\mu g/m^3$:	micrograms per cubic metre; a measure of particle or gas concentration in air.
10 minute mean:	average over a 10 minute period.
24 hour mean:	average over a 24 hour period.
95 percent CI:	95 percent confidence interval.
95 percent confidence interval:	the range of values within which the actual measure lies; it is based on the estimated value and the uncertainty of the estimate (std error). Where the confidence interval for a rate ratio excludes the value 1 we can be fairly certain that exposure is related to outcome (admission or death rates) in that study (i.e. $P < 0.05$).

KEY FINDINGS

Effects of Aircraft Noise

- Effects of noise exposure on humans are complex and a range of potential health-related effects of aircraft noise on communities has been identified in the available literature, including sleep disturbance, cardiovascular and physiological effects, mental health effects, effects on performance and effects on communication, residential behaviour and annoyance. The strength of scientific evidence for these has been reviewed resulting in available estimations of the change resulting from the New Parallel Runway (NPR) of:

  o Annoyance in dwellings;

  o Immediate sleep disturbance by single overflights;

  o Chronic sleep disturbance; and

  o Communication interference in schools (as a proxy for effects on cognitive performance of children) and community facilities.

- Analysis indicates that on opening of the NPR in 2015 there is estimated to be:

  o A minor net reduction of people annoyed and highly annoyed;

  o A minor net reduction of people little sleep disturbed, sleep disturbed and highly sleep disturbed;

  o An increase of 17 childcare and kindergartens subject to potential noise-induced awakenings;

  o An additional 5,000 shift workers potentially affected by daytime noise-induced awakenings resulting from aircraft noise. It is also estimated that there will 15,000 shift workers potentially effected by evening noise-induced awakenings;

  o A reduction of approximately 185,000 people potentially affected by night time noise-induced awakenings resulting from aircraft noise;

  o An increase of approximately nine schools subject to communication interference for the Summer Weekday Day; and

  o An increase of approximately seven places of worship subject to communication interference for the Summer Weekday Day. This increases to 27 for the Winter Weekend Day.

Exposure-effect relationships used in this assessment of the NPR have been developed from steady-state noise exposure situations. Human response to a step change (an increase or a decrease in noise exposure) is likely to be different to steady-state responses. Hence for all assessments, human reaction may be greater (or, respectively, smaller) as a result of the change than has been predicted. There is no evidence that if such 'over-reaction' occurs that it will attenuate over time.

In all of these noise assessments it should be noted that, because of variability in human response, effects will still be experienced by some people at lower levels (or a lower frequency of occurrence of overflights) outside the bounds of the noise metric used in each assessment, and effects may not be experienced by some people at higher levels (or a greater frequency of occurrence of overflights).

Effects of Aircraft Air Emissions

Approach

- A conservative approach was used to model the health impacts of ambient regional air pollutants from the proposed NPR. The pollutants considered were: benzene, CO, formaldehyde, NO2, PM10, PM2.5, toluene.
- The worst-case increases in air pollutants were used for assessing the potential worst-case health impact. Where improvements in air quality were forecast, they were not used to offset the worst-case estimates of adverse health effects.
- The models used for estimating the health effects were based on published: Epidemiological studies in Brisbane, other Australian cities or overseas cities; long term studies of mortality and lung function growth from the United States; and challenge chamber studies and panel studies. The health effects were modelled for the worst affected sites.
- Both acute and long term health effects were examined. The acute health effects examined were: Mortality and hospital admission; lung function, symptoms and GP visits. The long term effects considered were: Mortality; cancer incidence; and lung function growth in children.

Health Impacts

- Regional air pollution as a result of the NPR is not expected to have an impact on community health.
- In all cases the forecast increases in ambient air pollutants were small (0.0001 percent to 5.7 percent), relative the current air quality goals. The area forecast to experience the largest increase in ambient air pollutants was Nudgee Beach. However, there is a negligible increase in health risk.
- Benzene: The maximum forecast increases in cancer risk as a result of the NPR is one additional leukaemia case per 25 million people exposed to the worst-case increase in ambient annual average benzene over a 70 year period. This is a negligible increase in health risk.
- Carbon Monoxide (CO): The maximum forecast increases in cardiovascular hospital admissions as a result of the NPR is one additional cardiovascular admission per 50 million people exposed to the worst-case increase in ambient eight hour CO. This is a negligible increase in health risk.
- Formaldehyde: The forecast increase of formaldehyde as a result of the NPR is not expected to have an impact on health.
- Nitrogen Dioxide (NO2): The worst-case increase in long term health effects is likely to be negligible, since the forecast increase in ambient annual average NO2 is equivalent to 1 percent of the levels reported to have an adverse impact on lung function growth in children.
- Particulate Matter (PM10 /PM2.5): The increased mortality risk is one additional death per 100 million people exposed to the worst-case PM increase, while the most adverse increase in hospital admission is equivalent to one cardiovascular admission per 25 million people exposed to the worst-case PM10 increase. The long term effects of the increase in annual average PM10 as a result of emissions from the NPR are forecast to be extremely small.
- Toluene: The forecast increase of maximum 24 hour toluene as a result of the NPR is not expected to have an impact on health.
- Xylene: The forecast increase of maximum 24 hour xylene as a result of the NPR is not expected to have an impact on health.

7.1 Introduction to Health Impacts Assessment

This Chapter provides assessment of the health effects resulting from aircraft noise and emissions as a result of the New Parallel Runway (NPR). The aircraft noise health assessment is based on the modelling reported in Chapter D5 and the aircraft emissions health assessment is based on the modelling reported in Chapter D6.

7.2 Introduction to Effects of Aircraft Noise

Guidelines on limits to human disturbance from noise have often been established by compromise between scientific evidence and political/economic constraints, and their expression as *threshold criteria* in assessments can lead to problems of interpretation. In particular the community may incorrectly assume that there should be no incidence of adverse effects of noise where the noise exposure is below the threshold value (or conversely that there always will be effects of noise where the guideline is exceeded). The reality is that, for each effect of noise, there is an increasing incidence of effect with increasing exposure, and this is described by an *exposure-effect relationship*.

This assessment of the potential prevalence of noise effects from the NPR is based, where available, on *exposure-effect relationships* from the most recent noise research. For other effects, *exposure-effect relationships* are not available, and assessment still has to be guided by *threshold criteria* (or guidelines) drawn largely from World Health Organisation (WHO) guidelines, or Australian Standards, and the potential for misinterpretation of the extent of noise disturbance by their application has to be borne in mind.

Human disturbance effects and the health effects of noise are multidimensional and complex, and the scientific evidence is still not complete. The various effects are summarised in this report in the light of the current state of knowledge.

It will be seen that sufficient evidence for the estimation of human disturbance and health effects from aircraft noise using exposure-effects relationships is primarily in terms of:

- annoyance in residential settings;
- self-reported chronic sleep disturbance; and
- cognitive performance of children in schools.

7.3 Methodology for Assessing Effects of Aircraft Noise

An overview of human disturbance and health effects of aircraft noise is provided in section 7.4 below. Sections 7.5 to 7.8 report evidence for specific disturbances and effects, drawing material from two bodies of literature: noise and health, and aircraft noise and health. Examples of these sources are listed below:

- Recent reviews of noise and health:
  - a) Noise and Health (Health Council of the Netherlands 1994);
  - b) Community Noise (Berglund and Lindvall 1995);
  - c) Assessing Noise exposures for public health purposes (Health Council of the Netherlands 1997);
  - d) Health effects of noise on children and perception of the risk of noise (Bistrup 2001);
  - e) The health effects of environmental noise other than hearing loss (EnHealth Council 2004);
  - f) Assessment of health impacts and policy options in relation to transport-related noise exposures: Topic Paper Noise (Staatsen et al 2004);
  - g) Noise Pollution: non-auditory effects on health (Stansfield and Matheson 2003); and
  - h) Selection and evaluation of exposure-effect-relationships for health impact assessment in the field of noise and health. (Kempen et al 2005).

- Recent reviews of aircraft noise and health:
  a) Falling on Deaf Ears? (Department of the Senate 1995);
  b) Public health impact of large airports (Health Council of the Netherlands 1999);
  c) A review of health effects of aircraft noise (Morrell et al 1997);
  d) Literature review of health effects of aircraft noise for Second Sydney Airport EIS (Job et al 1997);
  e) Proposal for a Second Sydney Airport at Badgerys Creek or Holsworthy Military Area: Technical Paper 3. Noise: Volume 2: Health Effects of Aircraft Noise – Literature Review (Soames Job & Associates and PPK Environment & Infrastructure 1997); and
  f) Stansted Generation 1 Environmental Statement. Volume 2 Air Noise (BAA 2006).

Some of these provide extensive descriptions of human disturbance and health effects of noise. For example, Berglund and Lindvall (1995) provide a comprehensive discussion of the health impacts of community noise, assessing the scientific evidence pertaining to noise and health and attempting to identify, where possible, critical noise levels for health effects. The health effects of aircraft noise were also reviewed, in the Australian context, as part of the proposal for a Second Sydney Airport – reported in Technical Paper 3 of Volume 2: Health Effects of Aircraft Noise – Literature Review (Soames Job & Associates and PPK Environment & Infrastructure, 1997)

This report does not replicate the extensive documentation provided in these comprehensive reports but, in the following sections, briefly introduces the noise effects. This study focused on recent work, particularly on major overviews and meta-analyses, accessing the original studies cited in these works, and recent material published by key authors. Recent research includes at least one meta-analysis conducted with respect to most effects.

In addition to overviews, there is a range of individual studies on health effects that have been reported in recent years. However, in a practical assessment of potential health effects from the NPR, it is most appropriate to rely on the more robust results from the overviews and the meta-analyses, and it is findings from the latter that are included in the following sections.

The potential prevalence of human disturbance by noise from the NPR is estimated in section 7.10 by the overlay of predictions of future aircraft noise metrics on the location of residents and other receptors in the vicinity of the Brisbane Airport, and by application of exposure-effects relationships where these are available for particular effects, and by comparison to guidelines where they are not.

For details on the aircraft noise exposure predictions utilised in section 7.10, refer to Chapter D2.

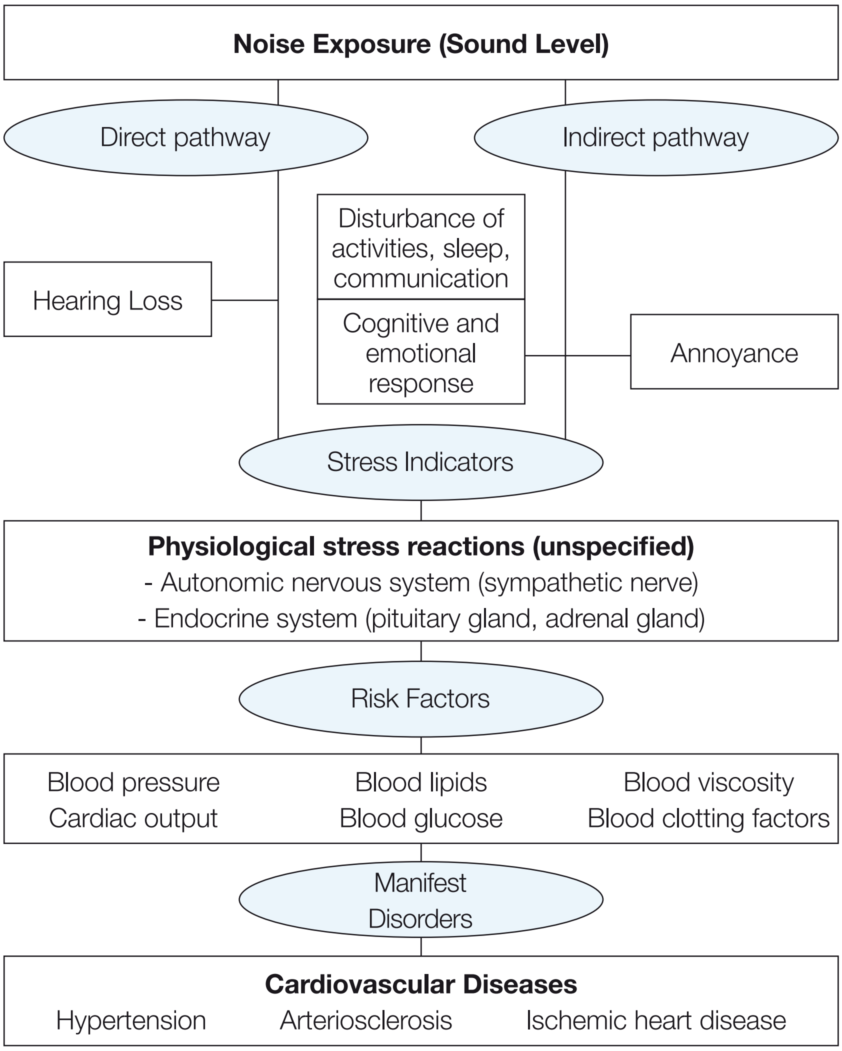
7.4 Overview of Human Disturbance and Health Effects of Aircraft Noise

The complexity of the effects of noise exposure on humans, and potential human health effects, is illustrated in Babisch's 2002 noise effects reaction scheme shown in **Figure 7.4**.

Figure 7.4 illustrates that noise can effect humans directly through a physiological pathway causing hearing loss, and indirectly through disturbance to normal human activities such as sleep, communication or concentration, and by generating an emotional response – annoyance. The combination of these effects can elevate the stress of the individual and this, along with other stressors and risk factors for the individual, may manifest in other disorders, particularly cardiovascular diseases. The management of noise is thus part of management of human health.

According to WHO (1946), health is "a state of complete physical, mental and social wellbeing and not merely the absence of disease or infirmity".

Figure 7.4: Noise Effects Reaction Scheme (Babisch 2002).



The WHO Community Noise Guidelines (Berglund et al 1999) note the following effects of noise and provides comprehensive summaries of each of:

- Noise-induced hearing loss;
- Interference with speech communication;
- Sleep disturbance;
- Cardiovascular and physiological effects;
- Mental health effects;
- The effects of noise on performance; and
- The effects of noise on residential behaviour and annoyance.

All aspects of Babisch's diagram have been the focus of research over many decades, and this is continuing, with more emphasis on large epidemiological studies that are necessary to test for links between noise and objective measures of human health. Sections 7.5 to 7.8 summarise the nature of particular noise effects, specific subgroups that may be vulnerable to that effect, and identify exposure-effect relationships for which there is sufficient evidence for use in assessment of the NPR. The strength of current scientific evidence across the different components of human reaction to noise is variable, but there is sufficient evidence now with respect to intermediate effects in the model – annoyance and sleep for example. Some effects are measured by self-report of those affected (e.g. subjective assessments of annoyance); others by objective measurement on those affected (e.g. sleep motility measurements).

7.5 Annoyance – Effect of Noise on Residential Behaviour and Annoyance

7.5.1 The Nature of the Effect

Annoyance can be defined as "a feeling of displeasure associated with any agent or condition, known or believed by an individual or group to adversely affect them" (Lindvall and Radford 1973; Koelega 1987 in Berglund et al 1999, page 32).

The term annoyance is often used to collectively refer to negative emotional responses to noise. These negative emotional reactions might also be described as anger, disappointment, dissatisfaction, withdrawal, helplessness, depression, anxiety, distraction, agitation or exhaustion (Job 1993; Fields et al 1997, 1998 in Berglund et al 1999). The noise reactions scheme shown in **Figure 7.4** shows that annoyance as an emotional response is linked with the disturbance of everyday activities such as communication and sleep.

Annoyance from noise has been associated with changes in individual behaviour which might include complaints, closing windows, not using outdoor areas and increasing the volume on television and radio. Further, chronic annoyance can lead to adverse effects on social behaviour including aggression, unfriendliness, disengagement and non-participation (Berglund et al 1999).

A significant amount of research has been undertaken into the nature and existence of annoyance from aircraft noise, in Australia (Job, 1996; Hede and Bullen 1982) and internationally (Meidema and Vos, 1999), identifying the variables that affect the annoyance response from noise exposure. These studies have revealed that the annoyance response is generated by a complex interaction of acoustical and non-acoustical factors.

Job (1996) reported that 10 to 25 percent of the variability of individual annoyance reactions can be explained by acoustical factors such as loudness, frequency and duration of the noise. Social surveys have revealed that annoyance is also a function of individuals' attitudes towards the noise source, their beliefs about how the noise source may affect them (including perceived social and economic advantages/disadvantages), feelings of helplessness in controlling the noise source and concerns about safety (e.g. fear of aircraft crashes). Meidema and Vos (1999) have particularly highlighted the important role of fear and noise sensitivity in the level of annoyance reaction to aircraft noise. Annoyance is measured by individuals self reporting their response on an annoyance scale, and there has been international agreement (e.g. International Organisation for Standardisation, 2003) on this measurement procedure and standardisation across different cultures and languages. While annoyance scores of individuals are measured, the prevalence of annoyance in populations has generally been reported in terms of the percentages of that population who are 'highly annoyed' and who are 'annoyed' – again considerable international standardisation has been achieved in defining these cut-offs.

7.5.2 Vulnerable Groups

Noise sensitive individuals, and those who have fears with aircraft safety, are more vulnerable to annoyance from aircraft noise. Exposure to vibration also exacerbates annoyance and individuals experiencing stress or mental illness such as anxiety and depression (at clinical or subclinical levels) are likely to report higher levels of annoyance.

7.5.3 Strength of Evidence of the Effect and Availability of Exposure-Effect Relationship

In Australia, the exposure-effect relationship for annoyance from aircraft noise that has been used to date has been based on the early work of Hede and Bullen (1982) though in their work the response effect was a multidimensional factor termed 'general reaction to noise' with 'annoyance' as one of the factors . The Australian Noise Exposure Forecast (ANEF) was the noise metric of exposure, and prevalence of effect reported in terms of the percentage of the population 'seriously affected' and 'moderately affected' by aircraft noise.

Currently, the most widely accepted exposure-effect relationships for annoyance from aircraft noise are those developed by Meidema and Oudshoorn (2001). Their exposure-effect relationships were developed to estimate the prevalence of annoyance from road traffic, aircraft and railways (different for each noise source) and are now recommended for noise assessment purposes by the European Commission (2002) (Environmental Noise Directive 2002/49/EC) and by the Environment Assessment Agency of the Netherlands (Kempen et al 2005). For aircraft noise, their relationship was based on a meta-analysis of 20 international studies. The list of the studies used in the analysis is shown in **Table 7.5**, and included 34,214 respondents across all surveys.

The noise metric used as the measure of exposure is the external L_{den} (this is the noise metric adopted under the European Union Environmental Noise Directive to harmonise environmental noise measurement and assessment across the European Union – it is an energy equivalent noise measure, with weightings for evening and night). The L_{den} has not found widespread use as yet in Australia.

The annoyance effect is defined as self-reported annoyance (a subjective measure of response) and is expressed in terms of the percentage of the exposed population who are highly annoyed (%HA) and the percentage who are annoyed (%A).

Table 7.5: Data Sets Used to Establish the Relationships Between Noise Exposure and Annoyance. From Miedema and Oudshoorn 2001, page 411.

Fields' code (6)	Name of survey (year)	Determination of DENL
Aircraft		
AUL-210	Australian Five Airport Survey (1980)	
	Richmond & Perth	*
	Sydney & Adelaide	DNL + 1.2
	Melbourne	DNL + 0.3
CAN-168	Canadian National Community Noise Survey (1979)	*
FRA-016	French Four-Airport Noise Study (1965)	*
FRA-239	French Combined Aircraft/Road Traffic Survey (1984)	
NET-240	Schiphol Combined Aircraft/Road Traffic Survey (1984)	
NOR-311	Oslo Airport Survey (1989)	*
NOR-328	Bodo Military Aircraft Exercise Study (1991- 1992)	*
NOR-366	Vaernes Military Aircraft Exercise Study (1990- 1991)	*
SWE-035	Scandinavian Nine-Airport Noise Study (1969, 1970,1971, 1972,1974, 1976)	*
SWI-053	Swiss Three-City Noise Survey (1971)	*
UKD-024	Heathrow Aircraft Noise Survey (1967)	
UKD-242	Heathrow Combined Aircraft/Road Traffic Survey (1982)	
UKD-238	Glasgow Combined Aircraft/Road Traffic Survey (1984)	
USA-022	U.S. Four-Airport Survey (phase I of Tracor Survey) (1967)	
USA-032	U.S. Three-Airport Survey (phase II of Tracor Survey) (1969)	
USA-044	U.S. Small City Airports (Small City Tracor Survey) (1970)	
USA-082	LAX Airport Noise Study (1973)	*
USA-203	Burbank Aircraft Noise Change Study (1979)	*
USA-204	John Wayne Airport Operation Study (1981)	*
USA-338	U.S.A. 7-Air Force Base Study (1981)	*

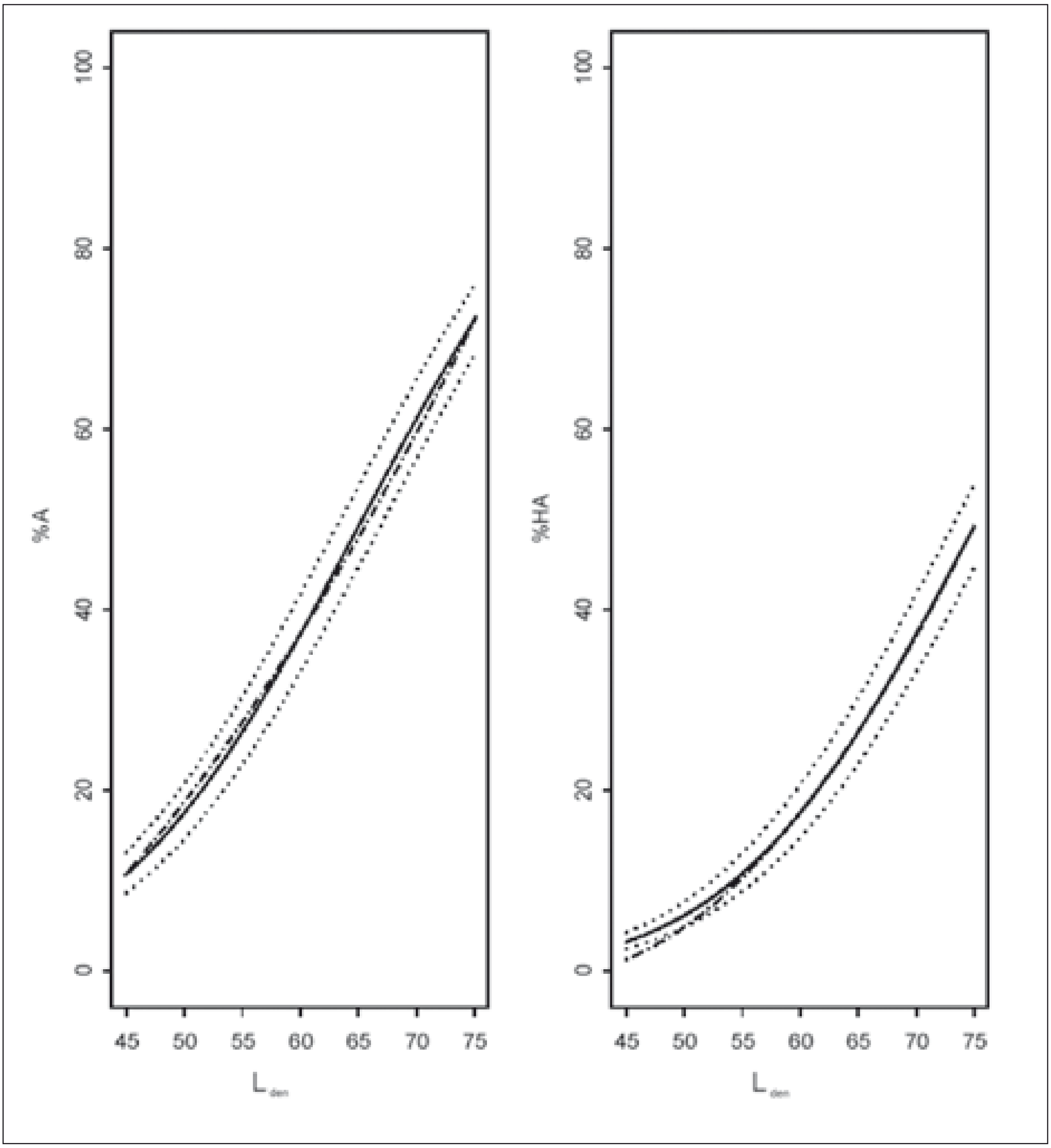
The exposure-effect equations for aircraft noise are shown in **Figure 7.5**, and the respective equations are:

$\%A = 8.588*10^{-6} (L_{den}-37)3 + 1.777*10^{-2} (L_{den}-37)^2+ 1.221 (L_{den}-37)$

$\%HA=-9.199*10^{-5} (L_{den}-42)3 + 3.932*10^{-2} (Lden-42)^2+ 0.2939 (L_{den}-42)$

In **Figure 7.5**, the solid lines are the estimated curves from the metal analysis, and the dashed lines are the polynomial approximations to this data. These relationships, unlike many before them, report the 95 percent confidence intervals – the dotted lines in **Figure 7.5** (Miedema and Oudshoorn 2000).

Figure 7.5: *Exposure-Effect Relationships for Self-Reported Annoyance from Aircraft Noise. Percentage of the Exposed Population Annoyed (%A) and Highly Annoyed (%HA). After Miedema and Oudshoorn (2001).*



A caveat to the use of these relationships is that they are designed to predict annoyance reactions in steady-state noise exposure situations rather than the short term effects of a change in noise climate.

In proposing the use of this exposure-effect relationship for assessment of the NPR, it is recognised that there are differences in urban form, use of the outdoors in residential areas, and housing design (particularly with respect to thermal insulation and hence potential acoustic insulation) between northern hemisphere cities and sub tropical Brisbane. However, there is no evidence from the research literature that these differences affect the exposure response relationship for annoyance. An Australian study was included in the derivation of the recommended relationship, and there is evidence that the windows in a majority of European dwellings are open to some extent, particularly at night (Passchier-Vermeer et al 2002).

An L_{den} of 55 closely equates to the ANEC 18 contour. Refer to section 7.10.1 for further analysis of affected populations.

7.6 Sleep – Effect of Noise on Sleep

7.6.1 Measurement of Night Time Noise Exposure

Before examining sleep disturbance, it is useful to consider the nature of aircraft flyovers, and the different ways of measuring noise exposure during sleep.

Figure 7.6a illustrates that aircraft noise is experienced by people as individual peaks of aircraft flyovers. These separate peaks can be measured by the maximum sound levels of each peak or by the Sound Exposure Level (SEL). The number of such peaks at different levels can also be counted. Overall, these peaks contribute to the total sound energy that is experienced by the sleeper (L_{night}).

Research on the complex field of sleep disturbance by noise has been conducted in the laboratory and in the field, and the current state of knowledge of the effect of night time aircraft noise shows that different effects on sleep depend variously on the maximum noise levels of noise events, number of events, event durations, and average noise exposure. The emergence of noise events in relation to the background level is also important. However, the knowledge of the relationships between noise exposure and all the different effects on sleep is still imperfect, and there is sufficient evidence for only certain aspects of sleep effects to be assessed (with different noise metrics required to assess different effects) for the NPR.

7.6.2 The Nature of the Effect

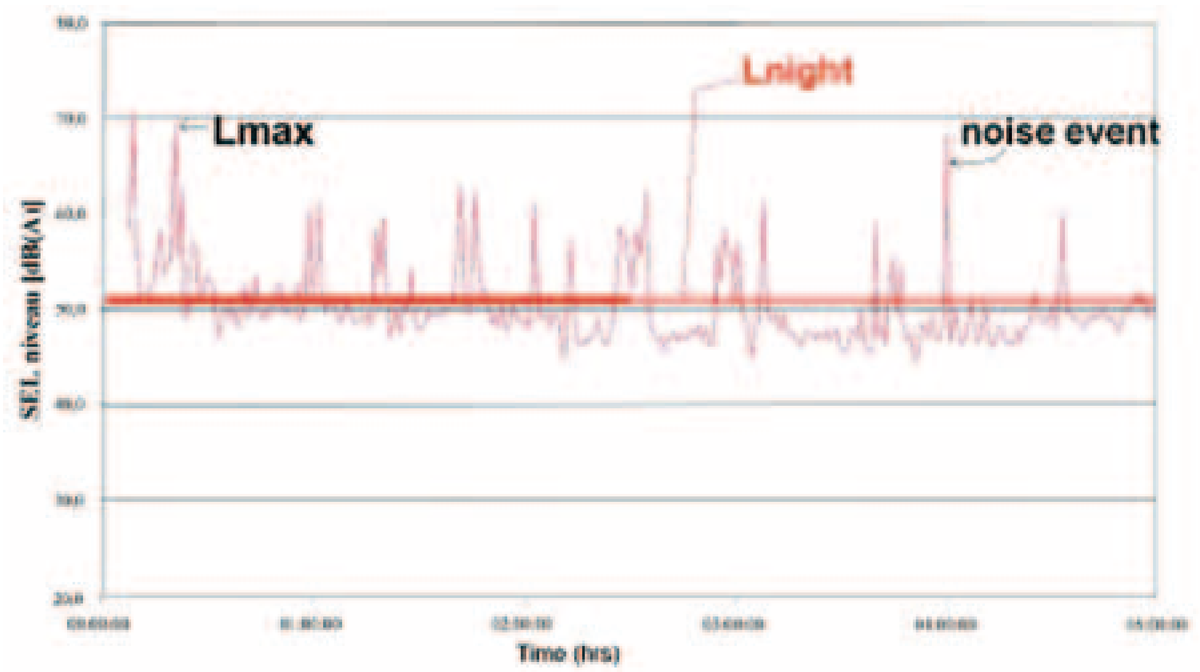
Porter et al (2000) has reviewed the adverse effects of night time aircraft noise and has developed a useful model to describe the range of potential impacts of night time aircraft noise on sleep. This model (**Figure 7.6b**) categorises the effects of night time aircraft noise as acute responses, total night effects, next day effects and chronic effects.

Acute responses include changes in blood pressure and heart rate, taking a longer time to get to sleep, awakening and acute annoyance (as a result of the awakening) and are experienced at the time of a particular aircraft overflight. These acute effects may aggregate over the night resulting in sleep fragmentation and changes in normal sleep cycles – termed 'total night effects'. The next day, the sleep-disturbed individual may experience fatigue, short term annoyance and changed mood that may all contribute to impaired performance. For exposure over a long period of time there is the potential for these effects to further aggregate and to have chronic effects on physical and mental health – termed 'chronic effects' of sleep disturbance.

The model illustrates that some of these responses and effects can be measured objectively: as sleep cycle changes monitored by electrocephalograph (EEG), body movements (motility) measured by actimetry, and noise-induced sleep disturbance by recording the actual number of times an individual awakens as a result of noise – say by activating a button when awoken. Objective measurements contribute significantly to our understanding of noise and sleep. Other effects can only be measured subjectively: for example by the use of questionnaires about sleep quality, or by sleep diaries. There are modifying factors that influence sleep (such as stress, existing sleep disorders

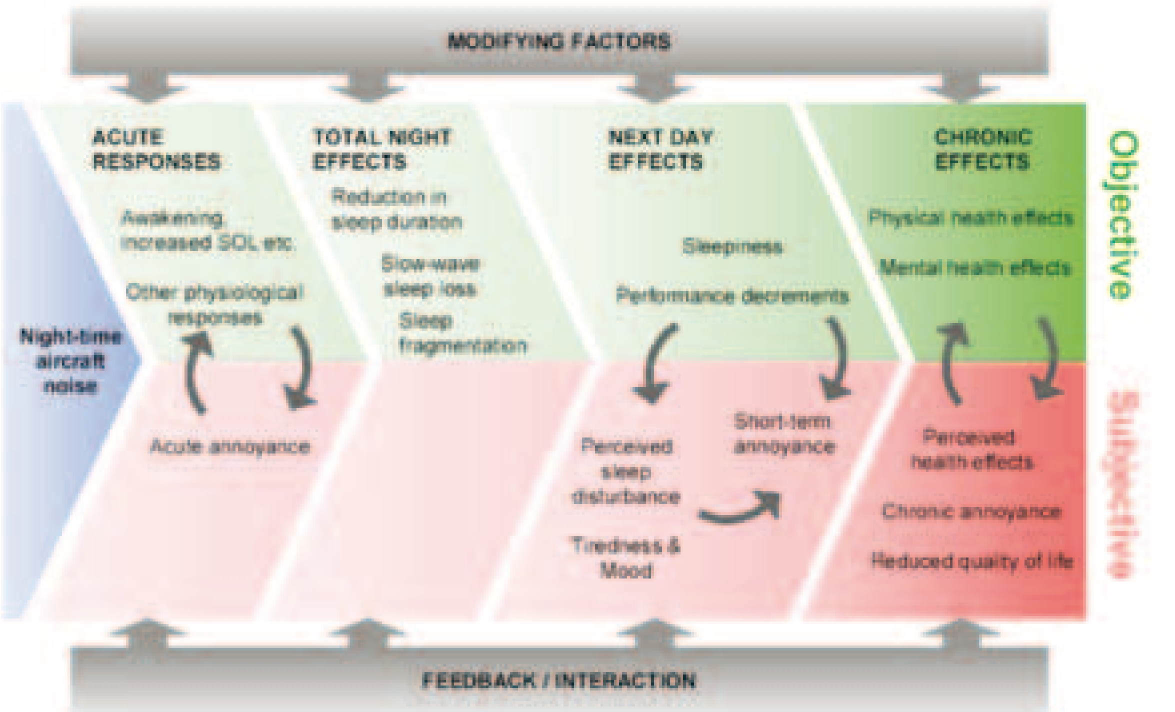
Figure 7.6a: *The Relationship Between the Peaks (L_{Amax}) of Noise Events, Sound Exposure Level (SEL) and L_{Aeq} for the Night Period (L_{night}). From European Commission 2004.*

Sound levels inside bedroom, window slightly open



Relation between L_{night} and L_{Amax} and SEL. This is a sound recording in a bedroom for one night. The top of the peaks are the L_{Amax}-levels, the total energy is the L_{night} (thick horizontal line). The sound energy in one event is the SEL (not represented, it is a calculated value over 1 second). In reality the L_{night} is the average of all nights over one year.

Figure 7.6b: *Potential Impact of Night Time Aircraft Noise and Sleep Effects: Model Framework. From Porter et al 2000.*



and illness) and interactions between the effects (e.g. noise-induced annoyance during the day may heighten annoyance at night).

7.6.3 Vulnerable Groups

Shiftworkers, elderly, children and those suffering from physical and mental illness are more vulnerable to the effects of noise-induced sleep disturbance (Berglund and Lindvall 1995).

7.6.4 Strength of Evidence of Sleep Effects of Noise

A substantial amount of research has been undertaken on noise and its effects on sleep in both laboratory and field studies. Useful reviews of this research can be found in Morrell and Taylor (1997), Berglund and Lindvall (1999), Porter et al (2000), Stansfeld and Matheson (2003), EnHealth Council (2004) and The Health Council of the Netherlands (2004).

The Health Council of the Netherlands (2004) report on "The Influence of Night Time Noise on Sleep and Health" represents the most state-of-the-art summary of the strength of scientific evidence relating to sleep effects of night time noise (**Table 7.6a**).

Table 7.6a: Summary of the Strength of Evidence of the Influence of Night Time Noise on Sleep and Health. After Health Council of the Netherlands, 2004.

ACUTE BIOLOGICAL EFFECTS		
Effect	**Strength of the evidence***	
Cardiovascular change	Sufficient	
Sleep stage change, from deeper to less deep sleep	Sufficient	
EEG awakening	Sufficient	
Motility	Sufficient	
Onset of motility	Sufficient	
Subject-registered awakening	Sufficient	
BIOLOGICAL EFFECTS BEFORE, WHILE AND AFTER SLEEPING		
Variable	**Strength of the evidence***	**Plausibility of influence on health and wellbeing**
Change in cardiovascular activity	Sufficient evidence	Plausible
Increased average motility (motility)	Sufficient evidence	Plausible
Changes in duration of various stages of sleep, in sleep structure, fragmentation of sleep	Sufficient evidence	Empirical data
Prolongation of the sleep inception period, difficulty getting to sleep	Sufficient evidence	Plausible
Changes in (stress) hormone levels	Limited evidence, plausible	Plausible
Immune functions	Insufficient evidence	–
Waking up in the night and/or too early in the morning	Sufficient evidence	Empirical data
Drowsiness/Tiredness during the day and evening	Sufficient evidence	Empirical data
Impaired cognitive performance	Limited evidence, plausible	Plausible
Increased irritability	Limited evidence, plausible	Plausible
Annoyance	Limited evidence, plausible	Plausible

EFFECTS ON HEALTH AND WELL-BEING OF PROLONGED EXPOSURE TO NOISE DURING THE SLEEP PERIOD (Chronic effects)		
Health endpoint	**Effect parameter**	**Strength of the evidence***
Sleep quality	Reduced perceived sleep quality	Sufficient evidence
	Difficulty getting to sleep, difficulty staying asleep	Sufficient evidence
	Sleep fragmentation, reduced sleeping time	Sufficient evidence
	Increased average motility when sleeping	Sufficient evidence
Well-being	Sleep disturbance	Sufficient evidence
	Health problems	Sufficient evidence
	Use of somnifacient drugs and sedatives	Sufficient evidence
	Increased daytime irritability	Limited evidence, plausible
Social contacts and concentration	Impaired social contacts	Limited evidence, plausible
	Impaired cognitive performance	Limited evidence, plausible
Medical conditions	Insomnia	Sufficient evidence
	Hypertension	Limited, indirect evidence, plausible
	Depression (in women)	Limited, indirect evidence, plausible
	Cardiovascular disease	Limited, indirect evidence, plausible
Reduction in life expectancy (premature mortality)	Occupational accidents	Limited, indirect evidence, plausible

**** Definitions for strength of evidence categories:***

Sufficient: *A causal relationship has been demonstrated between exposure to night time noise during the sleep period and a given effect. A relationship has been observed between exposure and effect in research which may reasonably be deemed to exclude the possibility of coincidence, bias and distortion, and it is plausible that the effect is attributable, at least in part, to the exposure.*

Limited: *A relationship between exposure and effect has been observed, and a causal relationship is credible, but the possibility of coincidence, bias or distortion cannot confidently be excluded. The presence of a relationship is generally plausible. No direct link has been established between exposure and effect, but there is good quality indirect empirical evidence for such a link and the presence of a link is plausible. Indirect evidence may be said to exist if it has been observed that exposure has an intermediary effect which is known from other research to lead to the ultimate effect under consideration.*

Insufficient: *The underlying research lacks the quality, consistency or weight necessary to support a conclusion regarding the existence of a causal relationship between exposure and effect. A link is not particularly plausible or is implausible.*

7.6.5 Availability of Exposure-Effect Relationships for Sleep Effects

There has been concerted effort to develop exposure-effect relationships for aircraft noise and sleep in recent years. The outcome of this effort is that there are now some exposure-effect relationships for aircraft noise that are recommended for noise assessment purposes by the European Commission (Environmental Noise Directive 2002/49/EC) and by the Environment Assessment Agency of the Netherlands (Kempen et al 2005). The availability of exposure-effect relationships for night time noise has been reviewed by Miedema et al (2003).

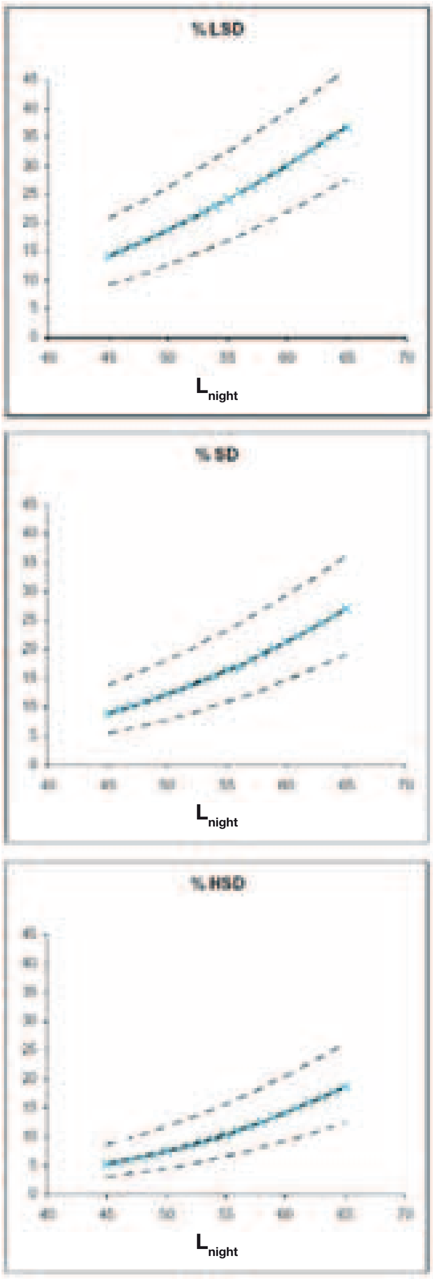
Two exposure-effect relationships for assessment of the NPR were adopted. The first can be used to estimate the prevalence of chronic sleep disturbance (as self-reported by those affected) over a long period of exposure to aircraft noise (aggregated sleep effects at the right-hand end of **Figure 7.6b**). The other provides an estimate of acute effects on sleep resulting from a single overflight (the left-hand end of **Figure 7.6b**) – viz changes in motility and noise-induced awakening.

7.6.5.1 Self Reported Chronic Sleep Disturbance

Meidema and Vos (2004) based a meta-analysis on nine sleep studies to develop exposure-effect relationships for self-reported chronic sleep disturbance – using aircraft noise studies from France, The Netherlands, Switzerland, the UK and the USA. The effect was long term sleep disturbance expressed in terms of the percentage of the population who reported themselves to be highly sleep-disturbed (%HSD), the percentage who reported they were sleep disturbed (%SD) and the percentage who reported they were a little sleep disturbed (%LSD).

The noise metric used in the meta-analysis was the total sound energy to which the respondents were subject during the night time hours (L_{night}) – see **Figure 7.6a**. The night time period was from 11pm to 7am. The relationships are shown in **Figure 7.6c**.

Figure 7.6c: *Self-Reported (chronic) Sleep Disturbance Related to L_{night}. The Three Curves Show the Percentage a Little Sleep Disturbed (%LSD), the Percentage Sleep Disturbed (%SD) and the Percentage Highly Sleep-Disturbed (%HSD). Confidence Limits (95%) are Also Shown. After Meidema and Vos (2004).*



The equations estimating the percentages sleep disturbed from the L_{night} noise exposure are:

$$\%HSD = 18.147 - 0.956L_{night} + 0.01482L_{night}^2$$
$$\%SD = 13.714 - 0.807L_{night} + 0.01555L_{night}^2$$
$$\%LSD = 4.465 - 0.411L_{night} + 0.01395L_{night}^2$$

7.6.5.2 *Motility and noise-induced awakenings*

Body movements (motility) occur 3 percent of the time during normal sleep (EC 2004) and motility has been found to be a sensitive measure for sleep disturbance because it is predictor for a range of effects – awakening, sleep quality, general health feelings (EC 2004).

Passhier-Vermeer et al 2002 and Miedema et al (2003) have developed a relationship for measured motility in response to noise showing increased incidence of bodily movement in response to increased level of the aircraft overflight. **Figure 7.6d** shows the probability of noise-induced motility related to the maximum noise level of an aircraft overflight, measured indoors.

Further, Passchier-Vermeer (2003) has conducted a secondary analysis of data for Schiphol airport and reported:

Percentage noise-induced awakenings
$= -0.564 + 1.909 * 10^{-4} * SEL_i^2$

where SEL_i is the indoor SEL of an aircraft overflight, and reports that this relationship is applicable to the general population exposed to commercial aircraft noise during the night time. **Table 7.6b** converts these SEL to L_{max} (indoors) using a conversion for typical aircraft noise overflights (reported in EC 2004).

Figure 7.6d: *Probability of (Aircraft) Noise-Induced Motility (M) at the 15 s Interval in Which the Indoor Maximum Sound Level Occurs (Solid Line) and the 95% Confidence Interval, as a Function of L_{Amax} Inside Bedroom. From Passchier-Vermeer et al (2002).*

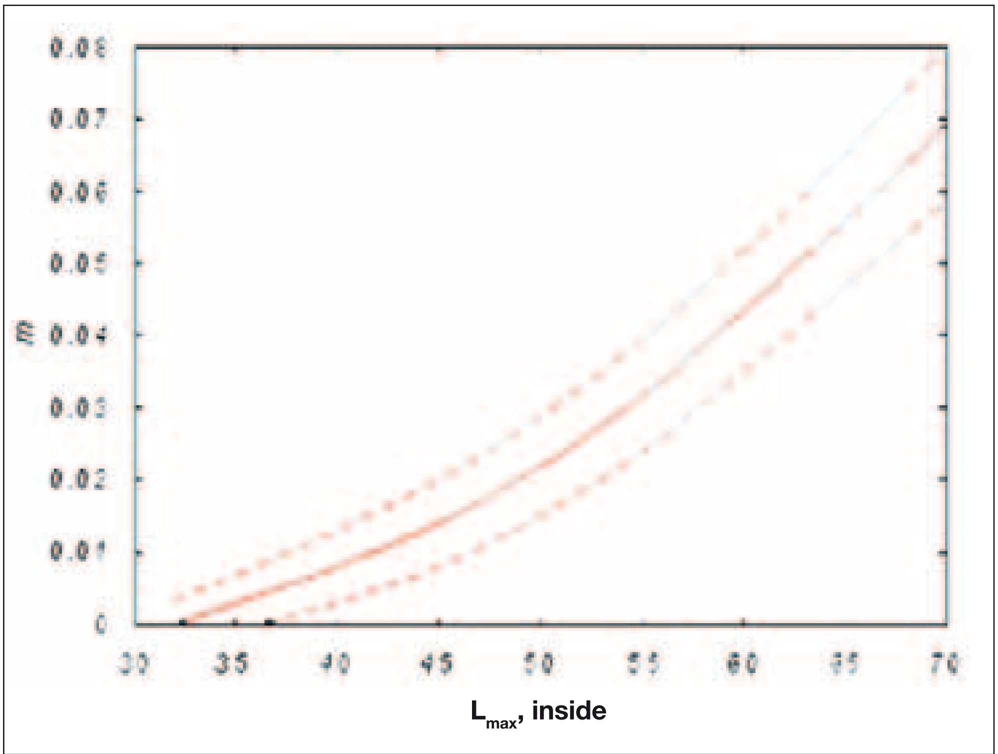


Table 7.6b: Percentage with Noise-Induced Awakenings in the General Population Exposed to Commercial Aircraft During the Night, for a Range of SEL/L_{max} – Calculated from the Passchier-Vermeer (2003) Exposure-Effect Equation

SEL (indoors)	L_{max} (indoors)	Percentage with noise induced awakenings
55	32	0.00
60	38	0.01
65	44	0.10
70	51	0.24
75	57	0.37
80	63	0.51
85	69	0.66
90	82	0.99

The motility and noise-induced awakening relationships provide evidence of an increasing effect of acute sleep disturbance from individual overflights with increasing maximum noise level of an aircraft overflight, but it is not possible to apply these in assessing the effect of the NPR. However the WHO Guidelines (Berglund et al 1999) for sleep suggest that maximum indoor noise levels should not exceed 45 dBA if sleep disturbance is to be avoided, and Australian Standard S2021 (Standards Australia 2000) recommends an L_{max} indoors of 50 dBA to avoid sleep disturbance.

For the purpose of assessment of sleep effects of the NPR, in addition to the estimation of the prevalence of chronic sleep disturbance caused by long term exposure to aircraft noise at night, an indication of the extent of immediate sleep effects caused by overflights can *approximately* be identified from the extent and frequency of occurrence of flights whose maximum noise levels exceed 60 dBA.

Figure 9.4a to **Figure 9.4e** in Chapter D9 identify the location of health, aged care and disabled facilities, child care centres, places of worship, educational facilities and recreation facilities in Brisbane, showing the change in noise contours resulting from the opening of the NPR.

For vulnerable groups such as shift workers, children in daycare and preschools, and residents in hospitals and nursing homes, the daytime period is also of interest.

7.7 Effects on Children

7.7.1 Nature of the Effect

There is evidence that children are particularly vulnerable to the effects of noise and that noise affects children differently from adults.

While children are susceptible to the same range of noise effects as adults (hearing impairment, annoyance, cognitive performance, sleep disturbance, elevated blood pressure and elevated stress hormone responses) there are environmental, physiological and psychological differences between adults and children that affect their noise exposure and their response. In summary, children are less able to control their physical environment, their noise exposure is different to adults, they may experience effects at lower levels of exposure and there is a greater risk of irreversible effects because they are still undergoing physical and cognitive development. Bistrup (2001) has summarized the characteristics of children in relation to noise. Refer **Figure 7.7a**.

Figure 7.7a: *Characteristics of Children in Relation to Noise. (Bistrup 2001)*

The following situations are relevant to the health of children in relation to noise:

- Some sounds may be noise to sensitive groups such as foetuses and the youngest children, although whether they find them unwanted cannot be measured directly.
- The circadian rhythm of children may influence children's susceptibility to noise.
- The threshold of what is perceived as noise varies greatly for healthy children and for healthy adults.
- Certain diseases or handicaps in children may lead to thresholds for the adverse effects of sounds that differ from those for healthy children.
- Special methods may have to be used to measure some adverse effects of noise in the developing child. New, perhaps less invasive, measurement methods could be applied. The methods should not interfere with the child's development. Measurements over time may be important for comprehending how noise affects a child's development.
- Children are forced to stay at locations defined by adults for much of their everyday life, such as homes, day care institutions and schools. Thus, children cannot generally avoid noisy environments in such settings.
- Children may be in environments that are not regulated at all or are not regulated to reflect children's susceptibility to noise, such as schools or day care institutions.
- Children can sometimes enjoy and be stimulated by sounds that some adults and some other children perceive as noise, such as toys with loud or special sounds or some types of music.
- Children depend on adults to advise them on protecting their hearing or prohibiting them from being exposed to hearing-damaging sounds, such as some fireworks and some loud music.
- Children depend on adults providing them with surroundings that support healthy development and learning and living, including conditions in day care institutions and in classrooms during teaching at schools.

7.7.2 Strength of Evidence and Availability of Exposure-Effect Relationship

Recent publications that have reviewed the research concerning the effects of noise on children include Health Council of the Netherlands 1999, Bistrup 2001, Stansfeld and Matheson 2003, Staatsen et al 2004, EnHealth Council 2004 and Zuurbier et al 2005. The recent findings of the RANCH project (Road Traffic and Aircraft Noise exposure and Children's cognition and Health) have been published by Stansfeld et al (2005).

The noise effects that have been considered in the studies of children and noise include outcomes related to physical health (blood pressure, stress hormones), quality of life and wellbeing (annoyance, motivation) and cognition (reading, memory, attention).

The details of the major studies that have considered noise effects on children are summarized in **Table 7.7**. The Los Angeles Airport Study, The Munich Airport Study, The Schools Environment and Health Study, The West London Schools Study and RANCH study have all considered aircraft noise.

There is consensus that children are 'vulnerable' to the effects of hearing impairment and sleep disturbance and that there is also sufficient evidence to relate chronic noise exposure to detrimental effects on the cognitive performance of children in schools. Reliable exposure-effect relationships are not available to estimate of the effect of noise on children's sleep (Zuurbier 2005). Hence, sleep disturbance effects on children cannot be assessed separately for the NPR.

Table 7.7: Summary of Health Outcomes Observed in Recent Field Studies in Children (+ = positive association observed, 0 = no association observed, - = negative association observed, NI = not investigated) (Staatsen 2004).

Study[a)]	Design	# schools	# children (age)	Exposure		
				Source	Metric	Range
LA-study	Cross-sectional /1-yr follow-up	7	262	Air	Peak sound level	High: 95 dB
Munich	Nat. experiment	-	326 (9-10yr)	Air	$L_{Aeq, 24 hrs}$	Gr 1 68/54 Gr 2 59/55 Gr 3 53/62 Gr 4 53/55[b)]
SEHS	Cross-sectional /1-yr follow-up	8	340 (8-11 yr)	Air	$L_{Aeq,16hr}$	High: > 66 dB Low: < 57 dB
WLSS	Cross-sectional	20	451 (8-9 yr)	Air	$L_{Aeq,16hr}$	High: > 63 dB Low: < 57 dB
Tyrol	Cross-sectional	26	1230 (8-11yr)	Rail, Road	L_{dn}	High > 60 dB Low < 50 dB
RANCH	Cross-sectional	89	2844 (9-10 yr)	Air, Road	$L_{Aeq,7-23hr}$	Air: 30-77 dB Road: 32-71 dB

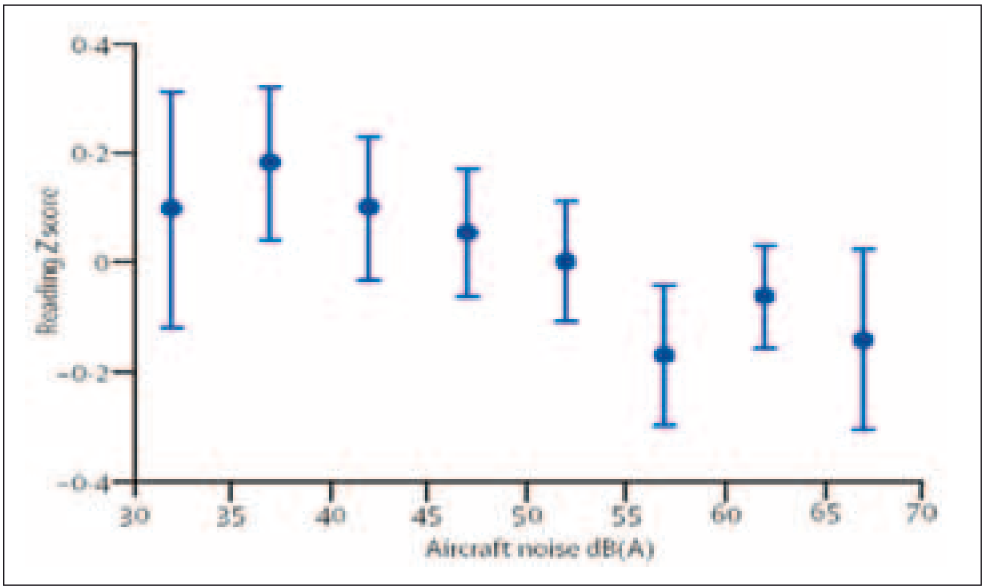
Study → / Outcome ↓	LA-study	Munich	SEHS	WLSS	RANCH	Tyrol
Summary of health/quality of life outcomes						
Annoyance	NI	+	+	+	+	+
Quality of life	NI	-	NI	NI	+	-
Motivation and helplessness	+	+	0	NI	NI	NI
Stress Hormones	NI	+	0	0	NI	+/0
Blood pressure	+	+	NI	NI	+/0	+
Summary of cognitive outcomes						
Reading	0	+	+/0	+/0	+	NI
LT-memory	NI	+	+/0	0	+	NI
Working memory	NI	+	NI	0	+	NI
Attention	+/-	+	+	0	-	0
Mental Health/behaviour	NI	+	0	+	-	NI

a) LA-study: Los Angeles Airport study (Cohen et al., 1980; Cohen et al., 1981). Munich: The Munich Airport Study (Evans et al., 1995; Evans et al., 1998; Hygge et al., 2002). SEHS: Schools Environment and Health Study: Haines et al., 2001ab); WLSS: The West London Schools Study: Haines et al.) Tyrol: The Tyrol Study: Lercher et al., 2002; RANCH: Stansfeld 2003, www.RANCHproject.org
b) Gr 1: noise levels of group old airport-aircraft noise before/after airport switch; Gr 2 noise levels of group old airport-no aircraft noise; Gr 3 noise levels of group new airport-aircraft noise; Gr 4 noise levels of new airport-no aircraft noise.

However, some exposure-effect relationships for cognitive effects have been produced by the RANCH project. It considered aircraft noise exposure and several measures of cognitive functioning of children in schools in the United Kingdom (UK), The Netherlands and Spain. The researchers concluded that chronic aircraft noise impairs reading comprehension and recognition memory in children. They also reported that chronic aircraft noise causes annoyance in children and that annoyance from aircraft noise was higher than annoyance from road traffic noise (Stansfeld 2005)

One output produced by the RANCH study is the exposure-effect relationship for chronic aircraft noise and reading score shown in **Figure 7.7b**. This relationship illustrates that reading score decreased with increasing levels of aircraft noise exposure.

Figure 7.7b: *Exposure-Effect Relationship (Exposure in Terms of L_{eq}) for Aircraft Noise and Reading (Stansfeld et al 2005, page 1945).*



The RANCH team has provided the following interpretation of its findings:

> *"Our findings indicate that a chronic environmental stressor – aircraft noise – could impair cognitive development in children, specifically reading comprehension. Schools exposed to high levels of aircraft noise are not healthy educational environments" (Stansfeld 2005, page 1942).*

While it is not possible to use this exposure-effect relationship for assessment in the NPR, the location of schools and other facilities that involve children where these effects could potentially occur can be estimated using the proxy of communication interference effects from aircraft noise (see section 7.8.2). The extent and frequency of communication interference can approximately be identified as those receptors for whom the maximum noise level from aircraft overflights exceeds 70 dBA.

7.8 Other Noise Effects

7.8.1 Impacts on Auditory Health

There is sufficient evidence that exposure to excessive noise has negative impacts on auditory health. These impacts include effects on hearing (noise-induced hearing loss) and sensory effects (aural discomfort and aural pain). These have been extensively investigated for noise exposure in occupational settings in order to develop legislation to protect workers (Berglund and Lindvall (1995). The human auditory system and the mechanisms of noise-induced effects on auditory health are comprehensively described elsewhere (e.g. Berglund and Lindvall (1995)).

Groups that are vulnerable to the effects of noise-induced hearing loss, include children (as their auditory mechanisms are still developing) the elderly (as hearing ability generally decreases with age), individuals with existing hearing impairment and individuals who are exposed to ototoxic drugs and chemicals (Berglund and Lindvall 1995). Hearing-aid wearers and sufferers of certain illnesses (Meniere's disease) are particularly vulnerable to aural discomfort and pain.

The WHO Community Noise Guidelines state that to protect against hearing impairment, L_{Aeq} (24 hours) should not exceed 70 dBA and L_{Amax} should not exceed 110 dBA. To protect against hearing impairment from impulse sounds, levels should not exceed L_{Amax} of 140 dB for adults and 120 dB for children. The threshold for aural discomfort in normal hearing persons is a SPL 80–100 dB while the threshold for aural pain in normal hearing persons is SPL of 110–130 dB. The vulnerable groups identified previously may experience noise-induced impacts on their auditory health at lower levels of noise exposure.

The impact of aircraft noise on auditory health has been considered by Morrell and Taylor (1997), the Health Council of the Netherlands (1999) and WHO (2001). Their conclusions are:

> *"Auditory effects of noise have been well described, but are not considered of importance in relation to exposure to civilian aircraft noise" (Morrell et al 1997, page 222).*

> *"Hearing loss is an auditory effect that is relevant for the exposure of airport and airline workers, but generally will not affect the hearing of the population in the vicinity of the airport giving the prevailing exposure levels" (Health Council of the Netherlands 1999, page 71).*

> *"Hearing loss is not relevant at noise exposure levels typically encountered around airports" WHO (2001, page 35).*

This evidence suggests that direct auditory effects will not be significant for environmental noise exposures from the NPR.

7.8.2 Interference with Speech Communication

Noise interferes with speech communication via a masking effect of the noise over the speech signal, making extraction of the speech sounds more difficult for the listener and this may require the speaker to use a raised voice. Communication disturbances not only affect direct human-to-human conversation, but can also disrupt common everyday activities such as hearing a radio or television and telephonic communication. These acute effects of communication disturbance, if experienced at a chronic level, can aggregate to "problems with concentration, fatigue, uncertainty and lack of self-confidence, irritation, misunderstandings, decreased working capacity, problems in human relations, and a number of reactions to stress" (Berglund and Lindvall 1995, page 52).

The hearing-impaired, the elderly, children acquiring language and children in schools are identified as being vulnerable to noise-induced communication interference.

The difference between the speech sound level (the signal) and the interfering sound (the noise) level is known as the signal-to-noise ratio and this ratio can be used to describe the relationship between noise and speech interference. A signal-to-noise ratio of 15–18 dBA is required if communication disturbance is to be avoided (for example, relaxed conversation outdoors occurs at a voice level of approximately 55 dBA and if the background level is 15–18 dBA lower, the speech will be 100 percent intelligible) (Berglund and Lindvall 1995). A noise event of 55 dBA will interfere with relaxed conversation outdoors (at this level the speech intelligibility is reduced to 95 percent which would be experienced as reliable but not comfortable conversation) (Berglund and Lindvall 1995).

Vulnerable groups need a 5–10 dBA larger signal to noise ratio to prevent disturbance. This means that for these vulnerable groups speech will be less than 100 percent intelligible when exposed to a noise event of 45–50 dBA.

Australian Standard AS2021 (Standards Australia 2000) recommends an L_{max} indoors of 60 dBA to avoid communication disturbance. DOTARS (2000) translates this to a maximum external single overflight level of 70 dBA. It can be seen that these levels fit reasonably with the evidence of the effect of aircraft noise levels communication disturbance.

For the purpose of the assessment of the NPR, an indication of the extent of immediate communication disturbance caused by overflights can *approximately* be identified from the extent and frequency of occurrence of flights whose maximum noise levels exceed 70 dBA. This is also the best measure for estimating potential impact on places of worship and any similar receptors where communication is important.

7.8.3 Cardiovascular and Physiological Effects

Physiological effects of noise include biological reactions presenting as reflex responses that occur immediately on exposure to noise and are accompanied by changes in several measures of physiological functioning including, increase in heart rate, increase in blood pressure and vascular constrictions. Startle reactions may occur if the noise is very loud and/or sudden (Berglund and Lindvall 1995). These biological reactions occur within two major physiological systems, namely the autonomic nervous system and the endocrine system. If the noise exposure is temporary, physiological functioning will return to pre-exposure levels within minutes of the exposure (Community Noise 1995, page 61), however chronic exposure will cause chronic stress in these systems which leads to threshold shifts in these measurements of physiological functioning that are accepted to be risk factors of cardiovascular diseases (Babisch 2006).

A recent review and meta-analysis of cardiovascular effects of noise exposure was conducted by Babisch (2006) and is the most up-to-date work available to evaluate the strength of evidence of cardiovascular effects of noise. Babisch considered the relationship between transportation noise and cardiovascular risk factors including mean blood pressure, hypertension, ischaemic heart disease, and, medication and drug consumption, and also considered vulnerable groups and analysed research pertaining to children and adults separately where possible. Babisch has provided some strong conclusions supporting the hypothesis that chronic noise exposure is causal in cardiovascular effects. The conclusions in relation to the effects of noise on cardiovascular health in children are:

> *"We know essentially nothing about the long term consequences of early noise exposure on developing cardiovascular systems. The degree of blood pressure elevations is small. The clinical significance of such changes in childhood blood pressure is difficult to determine. The ranges of blood pressure amongst noise-exposed children are within the normal levels and do not suggest hypertension. The extent of BP elevations found from chronic exposure are probably not significant for children during youth, but could portend elevations later in life that might be health damaging." (Evans and Lepore 1993 in Babisch 2006 Page 21). [However], "there is evidence that blood pressure level at an early age is an importance predictor of the blood pressure level at a later age" (Babisch 2006 Page 21).*

Conclusions in relation to effects of noise on cardiovascular health in adults are:

> *"there is no evidence from epidemiological data, that community noise increases mean blood pressure readings in the adult population. However, this does not discard the noise hypothesis as such. … it [is] more reasonable to look at manifest hypertension …rather than at mean blood pressure readings" (Babisch 2006, page 24).*

> *"with respect to aircraft noise and hypertension, studies consistently show higher risks in higher exposed areas" (Babisch 2006, page 29).*

> *"There is not much indication of a higher <u>ischaemic heart disease</u> risk for subjects who live in areas with a daytime average sound pressure level of less that 60 dBA across the studies. For higher noise categories, a higher IHD risk was relatively consistently found amongst the studies" (Babisch 2006, page 34).*

> *"All in all, the studies on the relationship between the use of medication or purchase of drugs and community noise support the general hypothesis of an increase in sleep disturbance and cardiovascular risk in noise-exposed subjects" (Babisch, 2006, page 35).*

Overall, there is scientific evidence that cardiovascular effects do result from chronic exposure to community noise, however, given the limited availability of exposure-effect relationships for aircraft noise and the health endpoint of cardiovascular effects, it is not possible to quantify this risk in relation to the NPR.

7.8.4 Performance Effects

Noise can impair a person's ability to perform complex tasks by disrupting communication and impairing cognitive functions relating to recall and memory. Secondary effects of noise exposure may also present as impaired performance (for example, a person who has their sleep period disturbed by noise may suffer impaired performance the following day).

The impacts of noise exposure on the ability of adults to perform complex tasks has been extensively investigated for occupational noise exposures (in relation to worker productivity in industrial settings) and although the results have been inconclusive, it has been shown that productivity levels increase when noise exposure is reduced by the use of hearing protection (Berglund and Lindvall 1995).

Performance effects from noise exposures are complex and are often the result of a primary disturbance such as communication interference (section 7.8.2) or sleep disturbance (section 7.6).

7.8.5 Mental health effects

The evidence concerning the relationship between noise exposure and mental illness has been reviewed by several authors (Berglund and Lindvall 1995; Morrell et al 1997; Stansfeld and Matheson 2003). Their conclusions are that the effects of noise on mental health are inconclusive, and that while noise exposure has not been shown to directly cause mental illness, individuals with existing mental illness (such as depression or anxiety) may be more sensitive to other effects of noise exposure.

7.9 Human Response to Changes in the Noise Exposure vs Steady State Response

The opening of the NPR will result in changes to noise exposure from aircraft noise for people in the surrounding community – some will experience an increase in exposure, some will experience a decrease as flight path configurations change. These can be considered as a step change in exposure as against a gradual change that may result from growth in air traffic at an airport over many years.

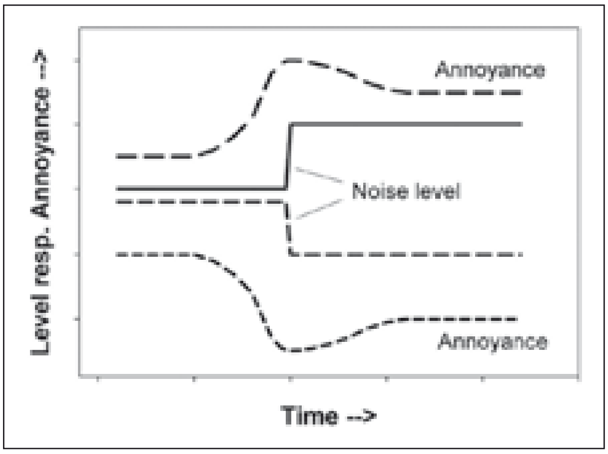
Brown and Kamp (2005) have reviewed the literature available on human response to such changes. They observe:

"Most information on the relationship between transport noise exposure and subjective reaction (annoyance/dissatisfaction) comes from steady state surveys at sites where there have not been step changes in noise exposure. Environmental appraisals often need to assess the effects of such step changes in exposure and there is growing evidence that when noise exposure is changed, annoyance-ratings may change more than would be predicted from steady state relationships.

"Conventional wisdom is that human response to a step change in exposure to transport noise can be predicted from exposure-response curves that have been derived from studies where human response has been assessed over a range of steady-state noise conditions. However, in situations where a step change in transport noise exposure has occurred, various surveys suggest that human response may be different, usually greater, as a result of the increase/decrease in noise, to what would be predicted from exposure-response curves derived under steady-state conditions. Further, there are suggestions that such (over)reaction may be more than a short term effect."

Guski (2004) describes this change effect in a hypothetical model (**Figure 7.9**), and also notes that where the noise situation is permanently changed, the annoyance of residents usually changes in a way that cannot be predicted by steady-state dose/response relationships. Most studies show an 'over reaction' of the residents – with increasing noise levels, people are much more annoyed than would be predicted by steady-state curves, and with a decrease of noise levels, people are much less annoyed. He also notes that the annoyance may change already before the change of levels, with residents expecting an increase of levels reacting more annoyed, and residents expecting a decrease in levels less annoyed than would be predicted in the steady state condition.

Figure 7.9: *Schematic View of Community Annoyance Changes with Step Changes of Noise Level (Guski, 2004).*



Brown and Kamp (2005) conclude:

> *"Our review of the literature on response to changes in noise leads us to the conclusion that we cannot discount the possibility that overreaction to a step change in transport noise may occur, and that this effect may not attenuate over time. However, evidence is still inconclusive, and based on limited studies that tend not to be comparable in terms of method, size, design and context. Further, our view is that most explanations given in the literature for an overreaction are only partly supported, in some cases not at all, and generally there is conflicting evidence for them. There is still also no accepted view on the mechanism by which annoyance changes in response to a change in exposure. In particular, most explanations are usually post-hoc and the noise change studies have not been designed to test them."*

The quantitative assessment of annoyance from the NPR in this report is based on relationships derived from studies of human reaction to steady-state noise exposure conditions. It is not possible to do otherwise given the current state of knowledge of human response in situations where the noise exposure changes, as will be the case for the NPR. However it needs to be recognised that the potential for 'over-reaction' to the change exists (people subject to an increase may experience more annoyance than predicted, people subject to a decrease may experience less annoyance than predicted). Further, any such over-reaction should not necessarily be assumed to be a temporary phenomenon – evidence from existing studies suggests that it could persist years after the exposure changes.

7.10 Assessment of the Effects of Noise for the NPR

7.10.1 Annoyance

The estimate of the percentage of the exposed population annoyed (%A) and highly annoyed (%HA) by aircraft noise is obtained by estimating the subpopulation that will be exposed to each particular value of L_{den} between 45 and 70 and multiplying this by the proportions shown in **Table 7.10a**.

Table 7.10a: Percentage Annoyed (% A) and Percentage Highly Annoyed (% HA) at various noise exposure levels (L_{den}).

L_{den}	Equivalent ANEC	%A	%HA
45	8	11	1
50	13	19	5
55	18	28	10
60	23	38	17
65	28	48	26
70	33	60	37
75	38	73	49

Analysis indicates that there is estimated to be a minor net reduction of people annoyed and highly annoyed on opening of the NPR in 2015. Refer to Chapter D5 for further discussion of suburb level changes.

7.10.2 Sleep Effects

7.10.2.1 Self-Reported Sleep Disturbance

Self-reported (chronic) sleep disturbance, in terms of the percentage of the exposed population who will report over a long period of time that their sleep is a little disturbed (%LSD), disturbed (%SD) and highly disturbed (%HSD) is obtained by estimating the subpopulation that will be exposed to each particular value of L_{night} and multiplying by the proportions shown in **Table 7.10b**.

Table 7.10b: Percentage Highly Sleep Disturbed (%HSD), Sleep Disturbed (%SD) and a Little Sleep Disturbed (%LSD) at various noise exposure levels (L_{night}).

L_{night}	%HSD	%SD	%LSD
45	5.1	8.9	14.2
50	7.4	12.2	18.8
55	10.4	16.4	24.1
60	14.1	21.3	30.0
65	18.6	27.0	36.7
70	23.8	33.4	44.1

Analysis indicates that there is estimated to be a minor net reduction of people little sleep disturbed, sleep disturbed and highly sleep disturbed on opening of the NPR in 2015. Refer to Chapter D5 for further discussion of suburb level changes.

7.10.2.2 Potential for Noise-induced Awakenings

The potential for noise-induced awakenings, or noise-induced motility during sleep, from individual aircraft overflights, can *approximately* be identified from the extent and frequency of occurrence of flights whose maximum noise levels exceed 60 dBA. This is also the best measure for estimating potential impact on day care centres (where children may be sleeping), nursing homes and hospitals (where sleep may occur at any time), and for potential effects on shift-workers.

The estimated change in the number of community facilities subject to potential noise-induced awakenings in 2015 is detailed in **Table 7.10c**.

Table 7.10c: Estimated Change in the Number of Community Facilities Subject to Potential Noise-Induced Awakenings in 2015 for Summer Weekday Daytime.

Facilities	Estimated Change in the Number of Community Facilities Resulting from Opening NPR in 2015 (Based on a change of 5 or more overflights)
Childcare and Kindergartens	+17
Hospitals	+1
Nursing Homes and Aged Care	-1
Retirement Homes	+1

Chapter D9 indicates that, in South Queensland, 60.9 percent of the population is in the workforce and that there is a range of between approximately 22 percent and 32 percent of the Brisbane workforce employed in shift work. The ABS publication Working Arrangements Australia (November 2003) indicates a national average of 14.1 percent of the population employed in shift work, although this varies by industry sector.

Analysis, based on 25 percent of the workforce in shiftwork, indicates that there is estimated to be an additional 5,000 shift workers potentially affected by daytime noise-induced awakenings resulting from aircraft noise on opening of the NPR. It is also estimated that there will be 15,000 shift workers potentially affected by evening noise-induced awakenings.

Analysis also indicates that there will be a reduction of approximately 185,000 people potentially affected by night time noise-induced awakenings resulting from aircraft noise on opening of the NPR.

The results presented above are similar for the equivalent typical busy winter weekday day and at weekends. Refer to Volume A, Chapter A2 for further details on busy days.

7.10.3 Effects on Children

It is not possible to provide exact estimate of effects on the cognitive performance of children in schools. However, the location of schools and other facilities that involve children where these effects could potentially occur can be estimated using the proxy of communication interference effects from aircraft noise. The extent and frequency of communication interference can approximately be identified as those areas where the maximum noise level from aircraft overflights exceeds 70 dBA. This is also the best measure for estimating potential impact on places of worship and any similar receptors where communication is important.

Analysis, based on a change of five or more overflights, indicates that there will be an increase of approximately nine schools subject to communication interference resulting on opening of the NPR for the Summer Weekday Day.

Analysis also indicates that there will be an increase of approximately seven places of worship subject to communication interference resulting on opening of the NPR for the Summer Weekday Day. This increases to 27 for the Winter Weekend Day.

In all of these assessments, it should be noted that effects will still be experienced, at a lower level or a lower frequency of occurrence, outside the bounds of the noise metrics shown, as described in the Introduction, section 7.2.

7.11 Introduction to Health Effects of Aircraft Air Emissions

The ambient air pollutants and ambient air toxics considered, and their applicability to aircraft emissions, are identified in Chapter D6.

Sections 7.12 to 7.14 provide details of the methodology adopted, information on health effects resulting from exposure to ambient air pollutants and ambient air toxics and a summary of the forecast health effects resulting from changes to ambient air quality resulting from the NPR.

7.12 Methodology for Assessing the Health Effects Resulting from Changes to Ambient Pollutants

A conservative approach was used to model the health impacts of ambient regional air pollutants from the proposed NPR. Predicted ground level concentrations for six specific sites and three time periods (2005, 2015 and 2035) were used to assess the effects of benzene, CO, formaldehyde, NO_2, PM_{10}, $PM_{2.5}$, toluene and xylene from the proposed NPR. Refer to Chapter D6 for further details on air emissions modelling.

The worst case increases in air pollutants were used for assessing the potential worst case health impact. Where improvements in air quality were forecast, they were not used to offset the worst case estimates of adverse health effects.

The models used for estimating the health effects were based on:

- published epidemiological studies in Brisbane, other Australian cities or overseas cities;
- long term studies of mortality and lung function growth from the United States; and
- challenge chamber studies and panel studies.

Where more than one health effect estimate was available the most conservative estimate, that is, the one that gave the largest adverse health impact, was used.

Consistent with the air emissions modelling in Chapter D6, the health effects resulting from predicted worst case emissions of the ambient pollutants, as noted above, from the proposed NPR were examined across the six ground level sites at:

- Eagle Farm;
- Hendra;
- Nudgee;
- Pinkenba;
- Wynnum; and
- Nudgee Beach.

The health effects were modelled for the worst affected sites. Both acute and long term health effects were examined.

The acute health effects examined were:

- Mortality and hospital admission; and
- Lung function, symptoms and GP visits.

The long term effects considered were:

- Mortality;
- Cancer incidence; and
- Lung function growth in children.

7.13 Health Effects of Ambient CO, NO_2, PM_{10} and $PM_{2.5}$ and Ambient Air Toxics Benzene, Formaldehyde, Toluene and Xylene

7.13.1 Carbon Monoxide (CO)

Carbon monoxide (CO) is an odourless, colourless and tasteless gas. It is produced by the incomplete combustion of fossil fuels. Carbon monoxide is absorbed through the lungs of humans and animals, where it reacts with haemoglobin (the oxygen-carrying molecule in the blood) to reduce the blood's oxygen-carrying capacity. Hence, it affects the delivery of oxygen to the body's organs and tissues. At concentrations exceeding about 100 cm^3/m^3 (0.01 percent) it is highly toxic. Its affinity for haemoglobin (with which it forms carboxyheamoglobin) is between 200 and 300 times that of oxygen.

The main source of carbon monoxide in the ambient air of a city, such as Brisbane, is petrol-fuelled motor vehicles; smaller quantities are produced by diesel-fuelled vehicles and other combustion processes. Motor vehicles account for up to 90 percent of all carbon monoxide emissions. Technological developments, such as improved engine design and catalytic converters, have reduced carbon monoxide emissions in recent years.

Carbon monoxide levels, therefore, tend to be greatest in areas of high traffic density.

7.13.2 Nitrogen Dioxide (NO_2)

Nitrogen dioxide is a brownish gas with a pungent odour. In the atmosphere, nitrogen dioxide exists in equilibrium with nitric oxide — a colourless, odourless gas. The mixture of these two gases is commonly referred to as nitrogen oxides, or NO_X. Nitrogen dioxide is produced from the combustion of fossil fuels. Motor vehicle emissions account for 70 percent of NO_2 production and NO_2 is a strong marker of road traffic. During high temperature combustion, NO_2, NO and other nitrogen oxides (NO_X) are generated. Part of the NO is converted to NO_2 through reactions involving oxygen and ozone. NO_2 is water insoluble and a strong oxidising agent, that may penetrate deep into the lungs. NO_2 and other NO_X are precursors for a range of secondary pollutants which have adverse effects on human health. In the presence of sunlight NO_X react with hydrocarbons and oxygen to form other photo oxidants, such as such ozone and nitric acid. There are often strong correlations between NO_2 and PM.

7.13.3 Particulate Matter (PM)

Particulate matter (PM) is a complex mixture of solids and/or liquids suspended in air. Airborne PM is produced through natural processes and as a result of human activity. Because Australia is a dry continent, its atmosphere contains a significant amount of particulate matter in the form of windblown dust. Bushfires, hazard-reduction burning in forests and agricultural practices also introduce particles into the atmosphere. In industrial and urban areas, the combustion of fossil fuels (e.g. by power stations and motor vehicles), industrial operations, incinerators and earth-moving activities all contribute to airborne particulate matter levels. Also, in coastal areas, the atmosphere can contain a significant level of sea-salt particles.

The size and composition of particulate matter is an important determinant of the health effects.

7.13.3.1 Size

Particle size is measured as the aerodynamic diameter of the particles and governs where the particles will be deposited in the respiratory tract and also the transport and removal of the particles from the air. The site of deposition in the respiratory tract influences the acute symptoms provoked, retention within the airways and possibly the long term health consequences. Based on aerodynamic diameter, particle pollution is divided into three groups PM_{10}, $PM_{2.5}$ and $PM_{0.1}$.

PM_{10} includes particles with an aerodynamic diameter of 10 µm or less and therefore measures of PM_{10} include $PM_{2.5}$ and $PM_{0.1}$ (**Figure 7.13a**). The precise definition of PM_{10} is particles that pass through a size selective inlet with a 50 percent efficiency cut-off at 10 µm aerodynamic diameter. Particles above 10 µm in diameter are predominantly deposited in the upper airways, such as in the nose, pharynx and trachea (**Figure 7.13b**). Particles between 2.5–10 µm are inhalable and are deposited in the in the larger airways (**Figure 7.13b**).

$PM_{2.5}$ is all particles equal to or less than 2.5 µm in aerodynamic diameter, or, more strictly, particles which pass through a size selective inlet with a 50 percent efficiency cut-off at 2.5 µm aerodynamic diameter. $PM_{2.5}$ is therefore a subset of PM_{10} (**Figure 7.13a**). Smaller particles referred to as respirable, range in aerodynamic diameter from 0.1 to 2.5 µm and are deposited deeper into the respiratory tract, such as the bronchi and alveoli of the lungs (**Figure 7.13b**). $PM_{2.5}$ have more adverse health consequences than larger particles and are released as a result of combustion processes, such as motor vehicle exhausts and solid fuel heaters.

$PM_{0.1}$, referred to as ultrafine particles, have an aerodynamic diameter of less than 0.1 µm. $PM_{0.1}$ is therefore a subset of both $PM_{2.5}$ and PM_{10} (**Figure 7.13a**). $PM_{0.1}$ account for the largest number of airborne particles, however the combined mass of these particles is often recorded as insignificant in comparison to the larger particles. Due to limitations in methods for quantifying ultrafine particles, very few of the studies have examined the role of ultrafine particles in health outcomes.

Figure 7.13a: *Categories of airborne particulate matter.*

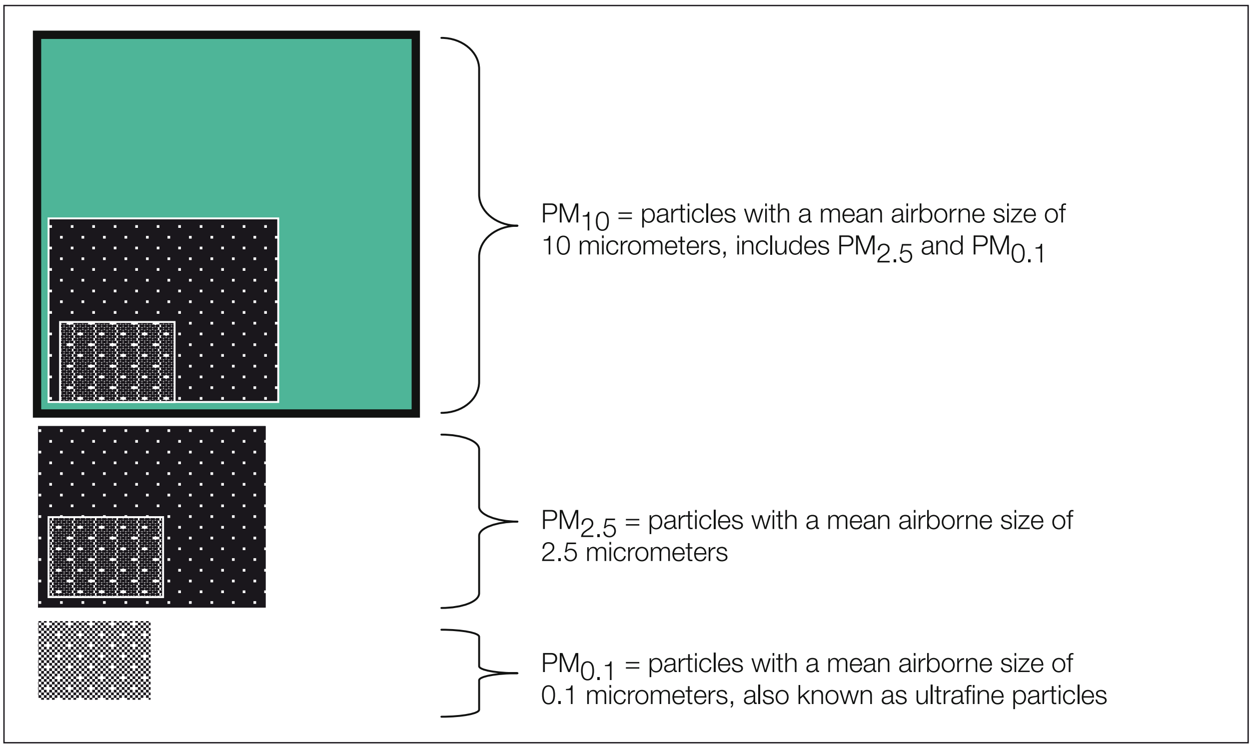
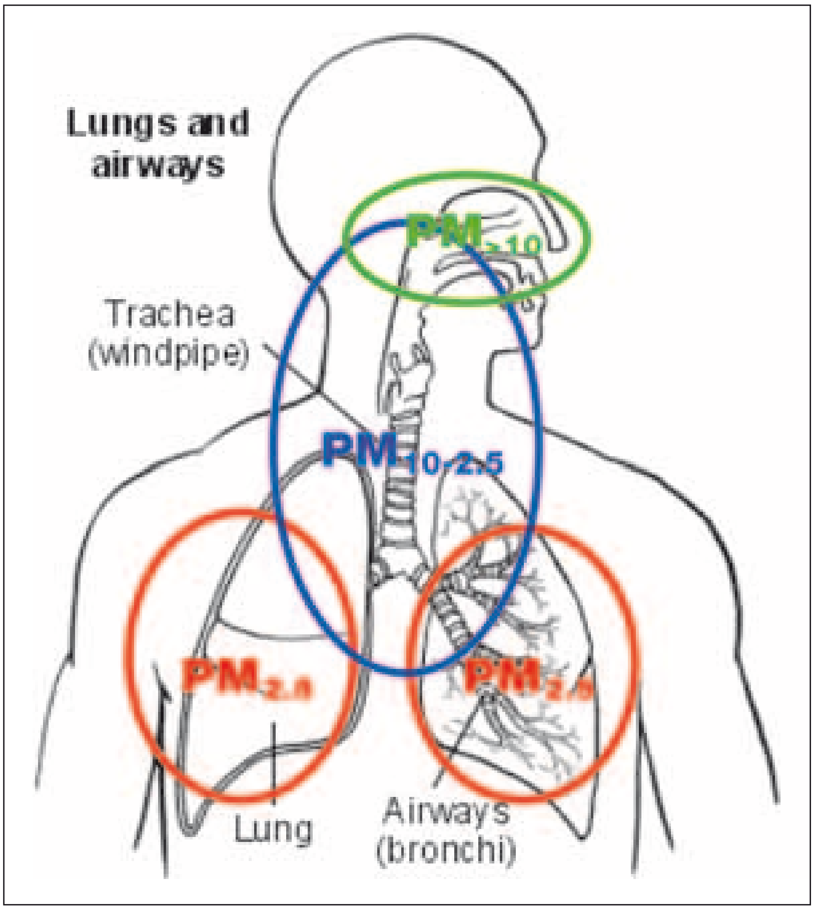


Figure 7.13b: *Penetration of particulate matter into the respiratory tract.*



7.13.3.2 Composition

PM can be either primary or secondary in nature. Primary particles are emitted directly into the atmosphere either by natural or man-made processes. Secondary particles have a predominantly man made origin and are formed in the atmosphere from the oxidation and subsequent reactions of sulphur dioxide, nitrogen oxides and volatile organic compounds (VOCs). The particles themselves are therefore a complex mixture of organic and inorganic compounds in solid or liquid states. Types of particulate pollution range from relatively large such as mineral dusts, such as occur during dust storms, to small particles released as a result of condensation of metals or organic compounds following high temperature combustion.

In addition to the different chemical composition of particles (as a result of their formation process) they may also be carriers of biological and non-biological mediators of inflammation. Biological mediators of inflammation include endotoxins and allergens, while non-biological mediators are some metal ions and polyaromatic hydrocarbons .

The ability of diesel particles to function as allergen carriers and to enhance the inflammatory response to allergens is well documented.

There also appears to be differences in the nature of the inflammatory response generated against smaller versus larger particles which are carrying allergen. While smaller particles carrying allergens may penetrate deeper into the respiratory tract they do not necessarily induce a greater immediate inflammatory response. In laboratory studies on cat allergic people with asthma, Lieutier-Colas et al (2003) found that 10 micrometer droplets of cat allergen were 20 times more potent than 1.4 micrometer droplets for inducing immediate inflammatory responses. The smaller particles, however, were more potent at inducing late inflammatory responses.

Metal ions have also been implicated in increasing the inflammatory properties of the inhaled particles. $PM_{2.5}$ particles rich in cadmium, nickel, zinc and copper were found to induce almost twice the inflammatory response as particles with lower levels of these metal ions.

7.13.4 Ambient Air Toxics Background

The Environment Protection and Heritage Council (EPHC) classify benzene, formaldehyde, toluene and xylene as air toxics. Air toxics are defined as gaseous, aerosol or particulate pollutants, which are present in the air in low concentrations with characteristics such as toxicity or persistence so as to be a hazard to humans, plant or animal life. The six criteria pollutants include particulate matter (PM_{10}), ozone, carbon monoxide, nitrogen dioxide, sulphur dioxide and lead.

Air toxics exist at relatively low concentrations in urban air sheds, with significantly elevated levels only occurring near specific sources such as industrial sites, heavily trafficked roads and areas impacted by wood smoke (NEPC, 2003). All are considered to be carcinogenic in some animals and all are classified by the International Agency for Research on Cancer (IARC) as carcinogenic for human beings, with varying degrees of certainty. Considering ambient concentrations, however, the risk is rather low.

The air toxics of particular relevance to this report (that is, air toxics that result from engine exhausts) are the Volatile Organic Compounds (VOCs). The VOCs are organic compounds in the boiling range of 50–260^{o}C and include chemicals such as benzene, toluene and xylenes. VOCs are a concern because of their potential to contribute to the formation of ground level ozone and to global warming. Some of the VOCs can also have more direct effects on human health, for example, the link between benzene and leukaemia.

Burning fuels containing carbon (gasoline, oil, wood, coal, natural; gas), and using solvents, paints and glues releases VOCs.

7.13.5 Benzene

Benzene is a natural component of crude oil. Almost all benzene found at ground level comes from human activities. It is emitted from industrial sources and a range of combustion sources including motor vehicle exhaust and solid fuel combustion. Benzene is also emitted from tobacco smoke. The major outdoor source is evaporative emissions and evaporation losses from motor vehicles, and evaporation losses during the handling, distribution and storage of petrol.

Petrol vehicle emissions are the predominant source of benzene in the environment (NICNAS, 2001) from (NEPC 2003). In the past, benzene has been widely used as a multipurpose organic solvent, however, this use has been actively discouraged (NEPC, 2003).

Benzene is naturally broken down by chemical reactions within the atmosphere. The length of time that benzene vapour remains in the air varies between a few hours and a few days depending on environmental factors, climate and the concentration of other chemicals in the air, such as nitrogen and sulphur dioxide.

7.13.6 Formaldehyde

Formaldehyde is a colourless gas with a strong irritant odour. Low levels of formaldehyde are produced as part of naturally occurring decomposition processes. In urban environments, formaldehyde emission sources include motor vehicle exhaust gases, domestic solid fuel and gas combustion, vapour release from goods manufactured using glues and resins containing formaldehyde and tobacco smoking (the last two sources being important indoor air quality issues). In addition, photochemical reactions involving oxidation of hydrocarbon compounds can produce formaldehyde. Formaldehyde is highly reactive and is important in photochemical smog formation.

7.13.7 Toluene

Toluene is a clear, colourless liquid with a distinctive smell. It occurs naturally in crude oil and is also generated through combustion of organic matter such as wood, coal and petroleum products. Motor vehicle emissions are the predominant source of toluene in the urban air environment, although evaporative losses from petroleum fuel storage facilities and service stations, and the use of toluene-based solvents and thinners are other contributors. Toluene is also a component of tobacco smoke. The highest concentrations of toluene usually occur in indoor air from the use of household products containing toluene (paints, thinners and adhesives) and cigarette smoke.

7.13.8 Xylene

Xylene is an aromatic hydrocarbon which exists in three isomeric forms: ortho-, meta- and para-xylene. The composition of xylene produced from petroleum is a mixture containing approximately 40 percent m-xylene and 20 percent each of o-xylene, p-xylene and ethylbenzene. Xylene occurs naturally in crude oil and is also generated through combustion of organic matter such as wood, coal and petroleum products. Motor vehicle emissions are the predominant source of xylene in the urban air environment. Evaporation from petroleum fuel storage facilities and service stations, and the use of products containing xylene-based solvents and thinners are other ways xylene enters the air environment.

7.14 Health Effects at Sensitive Receptors as a Result of Regional Changes in Pollutants

For the health effect modelling, the worst case forecast increases in emissions across the 6 sites occurred at Nudgee Beach in 2035 and were:

- Annual average benzene: 0.0015 ppb (0.005 µg/m^3);
- 8 hour carbon monoxide (CO): 0.04 µg/m^3;
- 24 hour formaldehyde: 0.22 ppb (0.27 µg/m^3);
- 1 hour maximum nitrogen dioxide (NO_2): 14 µg/m^3;
- Annual average NO_2: 1.4 µg/m^3;
- 24 hour PM_{10} µg/m^3: 0.4 µg/m^3;
- Annual average PM_{10}: 0.05 µg/m^3;
- 24 hour $PM_{2.5}$: 0.4 µg/m^3;
- Annual average 24 hour $PM_{2.5}$: 0.05 µg/m^3;
- 24 hour toluene: 0.0025 ppb (0.009 µg/m^3);
- Annual average toluene: 0.0003 ppb (0.001 µg/m^3);
- 24 hour xylene: 0.002 ppb (0.009 µg/m^3); and
- Annual average xylene: 0.0003 ppb (0.001 µg/m^3).

In all cases the forecast increases in ambient air pollutants were small (0.0001 percent to 5.7 percent), relative the current air quality goals.

7.14.1 Benzene

The forecast maximum increase in annual average ambient benzene as a result of the proposed NPR is 0.0015ppb (0.005 µg/m^3) at Nudgee Beach. It is known that a 1 µg/m^3 increase in benzene sustained over a 70 year period would result in approximately 8 additional leukaemia cases per 1 million people. The forecast worst case increase in annual ambient benzene is 0.0015 ppb (0.004 µg/m^3), and if sustained over a 70 year period this would be expected to result in approximately 0.04 additional leukaemia cases per one million people.

Based on the worst case scenario, the maximum forecast increases in cancer risk as a result of the proposed NPR is 0.04 additional leukaemia cases per one million people over 70 years, i.e. one additional leukaemia case per 25 million people exposed to the worst case increase in ambient annual average benzene over a 70 year period. This is a negligible increase in health risk.

7.14.2 CO

The worst case forecast increase in ground level CO was 0.04 mg/m^3 (0.034 ppm) averaged over an 8 hour period. The forecast 8 hour maximum CO level resulting from the proposed NPR is equal to 0.38 percent of the Australian Ambient Air Quality National Environment Protection Measure (AAQ NEPM) of 9 ppm. CO is known to have an impact on respiratory, asthma and cardiovascular hospital admission and cardiovascular mortality. However, the relatively small increase in CO as a result of the proposed NPR was predicted to result in an increase in hospital admission of between 0.001–0.002 persons/100,000 people exposed and an increase in cardiovascular mortality 0.0006 persons/100,000 people exposed.

Based on the worst case scenario, the maximum forecast increases in cardiovascular hospital admissions as a result of the proposed NPR is 0.002 persons/100,000, i.e. one additional cardiovascular admission per 50 million people exposed to the worst case increase in ambient 8 hour CO. This is a negligible increase in health risk.

7.14.3 Formaldehyde

The forecast increase of 0.22 ppb represents an increase equivalent to 0.55 percent of the AAQ NEPM Monitoring Investigational Level. The National Environmental Protection Council (NEPC) reported the lowest observable irritant health effects from formaldehyde to occur at concentrations between 0.08 and 0.1 ppm (80–100 ppb), which are more than 360 times higher than the worst case forecast increase from the proposed NPR.

The forecast worst case contribution of the proposed NPR to ambient 24 hour formaldehyde is not expected to have an impact on health.

7.14.4 NO_2

Both 1 hour average NO_2 and annual average NO_2 were forecast to increase as a result of emissions from proposed NPR. The predicted maximum level of 14 µg/m^3 (0.007 ppm) for 1 hour maximum NO_2 is equivalent to 10.3 percent of the highest one hour maximum recorded at the EPA's Brisbane CBD monitoring station in 2004 and 45 percent of the highest median one hour maximum recorded at the South Brisbane monitoring station.

Epidemiological models of the acute health effects of ambient NO_2 predict that on the days when the maximum increase in NO_2 occurs, there will be an increase in hospital admissions for cardiovascular, respiratory diseases in people aged 65 and over and asthma. There is also forecast to be an impact on mortality. The background rate of these events is relatively small and therefore the daily increase in each event is also small. The forecast incremental increase in hospital admission for cardiovascular diseases, respiratory admissions in people aged 65 and over and asthma are forecast to be 0.035, 0.016 and 0.03 persons per 100,000 people exposed to the maximum increase on the days when the maximum increases in NO_2 occurs. The incremental increase in mortality is forecast to be 0.016 person/100,000 people exposed to the worst case increase in NO_2.

A 1.4 µg/m^3 increase in annual average NO_2, as result of the proposed NPR was also forecast. Previous studies on the growth of lung function in adolescents living in different communities in southern California have found that a 72 µg/m^3

increase in annual average NO_2, over an eight year period, resulted in a 6 percent increase in the number of 18 year olds who had a clinically significant lower lung function. Based on the forecast annual average level of NO_2 and the published Californian studies, the increase from the proposed NPR is around 1 percent of the value reported in Californian study and is therefore not likely to have a significant impact on lung function growth of adolescents.

The worst case increases in acute adverse health events resulting from increases to ambient NO_2 from the proposed NPR are forecast to be very small. For every 2.9 million people actually exposed to the worst case increase in NO_2 on that day, one additional cardiovascular hospital admission is forecast. For every 6.3 million people exposed to the worst case increase in NO_2 on that day, one additional death is forecast. These are negligible increases in health risk.

The worst case increase in long term health effects is likely to be negligible, since the forecast increase in ambient annual average NO_2 is equivalent to one percent of the levels reported to have an adverse impact on lung function growth in children.

7.14.5 PM_{10}

For PM_{10} a the worst case increase in 24 hour concentration was forecast to be 0.4 µg/m^3, while the worst case annual average was forecast to be 0.05 µg/m^3. The increase in daily PM_{10} is forecast to result in small increases in the risk of mortality, asthma, cardiovascular and respiratory admissions to hospital and visits to the doctor for asthma. However, the increased risk of these events is small. For hospital admissions, the increased risk ranges from 0.001 to 0.004 persons per 100,000 people exposed on the days when the maximum increase in PM_{10} actually occurs. For mortality the increased risk is 0.001 persons per 100,000 exposed. Small increases in GP visits for asthma and in respiratory symptoms are also forecast.

A long term effect on lung function growth in children is predicted based on studies performed in southern California, where a 51.5 µg/m^3 increase in annual average PM_{10} exposure over an 8 year period was associated with 6 percent more children having a clinically significant reduction in lung function by age 18 years. The forecast increase in annual average PM_{10} for 2035 resulting from the proposed NPR is 0.05 µg/m^3, which represents 0.1 percent of the increment recorded in the Californian studies. Based on Californian studies and the worst case predicted PM_{10}, the percentage of children living at Nudgee Beach that would have clinically reduced lung function as a result of the forecast increase in annual PM_{10} from emission from the Proposed NPR is predicted to be negligible.

Small increases in the risk for mortality, hospital admission and respiratory symptoms have been determined. The increased mortality risk is one additional death per 100 million people exposed to the worst case PM_{10} increase, while the most adverse increase in hospital admission is equivalent to one cardiovascular admission per 25 million people exposed to the worst case PM_{10} increase.

The long term effects of the increase in annual average PM_{10} as a result of emissions from the proposed NPR are forecast to be extremely small.

7.13.6 $PM_{2.5}$

Consistent with the worst case scenario, it was assumed that the forecast increase of 0.4 µg/m^3 in 24 hour PM_{10} was all due to $PM_{2.5}$. There is less known about the health effects of $PM_{2.5}$, since until recently $PM_{2.5}$ was not extensively monitored. A study of three Australian cities, not including Brisbane, found a10 µg/m^3 increase in $PM_{2.5}$ resulted in a 5.1 percent increase in cardiovascular admission in all ages, while there was no significant effect on total mortality. Studies in Melbourne, which approximated levels of $PM_{2.5}$, reported a 15 µg/m^3 increase in $PM_{2.5}$ was associated with a 2.4 percent and 13.9 percent increase in all respiratory and asthma admissions, respectively. Based on a 0.4 µg/m^3 increase in $PM_{2.5}$, the potential adverse health effects are therefore equivalent to increases in hospital admissions of between 0.002–0.004 per 100,000 people exposed.

The long term effect of a 0.05 µg/m^3 in annual average $PM_{2.5}$ is a 0.016 percent increase in total mortality.

There is a negligible increase in cardiovascular admissions equivalent to one additional hospital admission per 33 million people exposed to the worst case increase in $PM_{2.5}$. Smaller increases in hospital admission for asthma, and all respiratory conditions and mortality are also forecast.

7.13.7 Toluene

The forecast increase of 0.003 ppb (0.009 µg/m^3) represents an increase equivalent to 0.0003 percent of the AAQ NEPM Monitoring Investigational Level, which was set in consideration of no adverse health effects.

The forecast worst case contribution of the proposed NPR to ambient 24 hour toluene is not expected to have an impact on health.

7.13.8 Xylene

The forecast increase of 0.002 ppb (0.009 µg/m^3) for maximum 24 hour xylene represents an increase equivalent to 0.0008 percent of the AAQ NEPM Monitoring Investigational Level, which was set in consideration of no adverse health impacts.

The forecast worst case contribution of the proposed NPR to ambient 24 hour xylene is not expected to have an impact on health.

7.15 Summary of Health Effects Resulting from Changes to Ambient Pollutants

Regional air pollution as a result of the proposed NPR is not expected to have an impact on community health. The assessment was based on the worst case forecast changes in regional ambient benzene, carbon monoxide, formaldehyde, nitrogen dioxide, coarse and fine particulate matter, toluene and xylene as a result of the proposed NPR.

The worst case changes in ambient air pollutants were forecast to be very small and were equivalent to 0.0001 percent to 5.7 percent of the National air quality goals. These worst case increases were used to predict the acute and chronic health impacts based on a range of known published relationships between air pollutants and health.

The increased risk of an acute adverse health events, such as hospital admissions or mortality were correspondingly small, in the order of 1 in 3 million to 1 in 167 million on the day and at the location where the forecast worst case occurs. The forecast impact on symptoms of asthmatic children, a sensitive subgroup within the community, was also found to be small, representing a worst case acute effect of a 0.03 percent increase in lower respiratory tract symptoms. Long term health effects on cancer, mortality and lung function growth in children were also forecast to be negligible.

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