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ILLUSTRATIONS

1 INTRODUCTION

Research carried out for the Wilson Report published in 1963 established that there were a wide range of environmental noise problems in this country and that there was considerable potential for these problems to increase without determined action (WILSON 63). Despite a great deal of subsequent research and development, a considerable investment in noise control technology, a wide-ranging technical debate nationally and internationally, and many new standards and regulations, quite a few of these problems are still outstanding (BERRY 97). The most recent national noise survey carried out in 1990 showed that average noise levels outside houses had hardly changed since an earlier survey carried out 18 years earlier in 1972 (SARGENT 93). At the same time noise complaints to local government, airports, industry and others continue to increase. The problem of noise has not been solved.

Noise control is not simply a matter of setting targets and then taking action as required because there are often severe technical, economic and social constraints on what can be achieved in practice. While the costs of noise control are usually more or less tangible, the benefits must be carefully weighed against these costs, and this is hard to do when the most widely used indicator of noise effects is simply "annoyance". It is clear that a general change-over to some more concrete indicator of effects such as effects on health, might enable future noise targets to be defined with greater transparency. Monetary evaluations of noise effects would also be attractive but there is little evidence that any progress can be made in this area, at least in the short to medium term.

The 1996 Green Paper "Future Noise Policy" (EC 97) shows that the European Commission is moving towards noise control action as a response to increasing concerns of possible health effects. The EC is working towards a Directive to harmonise noise assessment methodology, to establish target values, and to oblige member states to take action to reach such targets. Noise guidelines based on a liberal interpretation of health effects, reported and edited on behalf of WHO by Berglund and Lindvall (BERGLUND 95), appear to have been influential in the development of the Green Paper. However all such guidelines are open to different interpretations. Other recent documents, such as the review published by the Health Council of the Netherlands, also examine the issues of noise and health. The topic of noise and health was discussed in depth at a workshop on Non-auditory Health Effects of Noise held in Leicester in May 1997. A large number of future research requirements and topics were identified, illustrating continuing scientific uncertainty in this general area (IEH 97).

In view of these developments, the idea of standards which are closely linked to possible health effects requires critical investigation. The National Physical Laboratory (NPL), together with the Institute of Sound and Vibration Research (ISVR) began a project in January 1998 for the UK Department of the Environment, Transport and the Regions (DETR) to review noise standards used for assessing the health impact of environmental noise. The objectives of the project were set out to:

- consider existing information to establish noise levels at which there may be particular effects on the population, and from this,

- advise on the feasibility of establishing effects-based standards which could be used to inform the setting of objectives and targets.

Put as simply as possible, the DETR want to know how, or even whether it is possible, to derive robust health effect based noise standards. Do health effects actually exist at typical levels of environmental noise and if so, can they can be reliably quantified? What other factors should be considered in establishing practical effect-based assessment methods?

The starting point is a summary of current knowledge of health effect based noise assessment methods, based on previous reviews. In the time available, it has only been possible to extract the key information required to address the defined objectives. This study then goes beyond previous reviews by examining the feasibility of establishing effect based standards. Both the available scientific evidence and the practicality of existing regulatory noise limits are found to be relevant.

Section 2 sets out the work strategy and explains how the work was done. Section 3 examines the scientific evidence underlying the relationship between noise and health. It considers the concept of health, the potential and actual impacts of noise on health, and the levels suggested by research below which these effects are unlikely to be observed. This section also looks at the uncertainties associated with relating the separate effects to an overall impact on health.

Section 4 looks at practical noise criteria and how these differ from those based on scientific evidence alone. It briefly reviews the environmental noise regulations and standards used in the UK and other EU countries and comments on the extent to which these are based on scientific data alone, or on other factors.

Section 5 offers guidance for the interpretation of the WHO guideline criteria. It is important that the WHO guidelines are properly understood in the context in which they were written. Section 6 summarises the key findings of the study. Section 7 considers the way ahead.

References to published literature are listed at the end of the report. The list is arranged alphabetically, with details given in the text in brackets using the first named author and year of publication. Throughout this report the term 'standard' is used to describe an assessment method, whereas it can also mean a British, European, or International standard.

2 WORK STRATEGY

Phase 1- Review
The review phase was split into three stages;

- a review of literature on **the known effects of environmental noise,**

Existing reviews of the effects of environmental noise were consulted in some depth. Close examination of the Health Council of the Netherlands study (NETHERLANDS 94) showed much commonality with the objectives of this study. The Health Council of the Netherlands were tasked to consider:

" What health effects are to be expected from exposure to noise at different sound levels ?" and *" What health-based exposure limits can be derived from these data ?"*

In view of the significant amount of work which had already been done, this review took the Health Council of the Netherlands report as the starting point. Further reviews carried out since 1994 were then consulted. The key reviews are summarised in table 1 below;

Table 1: Key review papers

Reference	Summary information
BERGLUND 95	Berglund and Lindvall examined the effects of noise in the community for the WHO. They link potential health effects to noise immission in the environment rather than to noise emission from specific sources.
JOB 95	Job outlines a model of the potential psychological factors and their possible causal roles in the production of noise related health effects.
JOB 96	Job extends the 1995 work to explore the potential causal link between noise exposure in a residential setting and detrimental health effects.
SHAW 96	Shaw looks at the effects of various levels of noise exposure on human activities and health. He considers criteria and guidelines based on social studies.
THOMPSON 96	Thompson updates her earlier reviews of noise and health by looking at the potential modifiers to the relationship between noise and health indicators and views these as intervening factors in the casual chain which either reinforce or diminish the original stress response.
BERGLUND 96	Berglund reviews the concept of health, health effects of community noise and environmental health control in the context of aircraft noise. It looks at dose-response relationships, vulnerable groups and threshold levels. The work appears to be very largely based on BERGLUND 95.
MORRELL 97	Morrell examines evidence for health effects due to aircraft noise.
NETHERLANDS 97	This report proposes a system of environmental noise exposure metrics for risk assessment of and policy decision-making on the

	adverse effects of environmental noise on health and the well-being of residential communities. One chapter is dedicated to the effects of environmental noise exposure.
LUDLOW 97	This paper outlines the uncertainties which make the interpretation of epidemiological studies into noise and health effects difficult. It looks briefly at the evidence for health effects of noise and proposes alternative research approaches to examine causative mechanisms between noise and health.
IEH 97	This report is based on review papers prepared for a workshop on non-auditory effects of noise. One paper by Stansfeld reviews environmental noise and health. Summary reviews on noise exposure and specific effects are also given. The available evidence is critically reviewed and recommendations made for future research.

- a review of **current standards and noise criteria or limits** in operation in the UK and other EU countries,

This stage had two main aims; to summarise the standards and limits used to control environmental noise in different countries, and to understand where possible the origin and justification for any resulting numerical noise limits or targets.

The starting points for this stage of the study were two key publications. In 1994 Dieter Gottlob of the German Federal Ministry of the Environment presented the results of an extensive review of community noise regulations (GOTTLOB 95). In 1995 work was completed at NPL on a review of national practices on the assessment of industrial noise (PORTER 95). For this project, updated information was sought from national experts across Europe. Three main areas in the measurement and assessment of environmental noise were followed up:

1. the legislative or regulatory framework,
2. any noise limits where specified to include indicators used (noise units),
3. relevant research findings or other information against which the national standards criteria or limits had been developed.

The information was requested in tabular form where possible. Copies of the written request for information, including an example table, are reproduced in Appendix I. The results are presented in section 4.2.

- a review or **"guide to interpretation" of the 1995 WHO Community Noise Guidelines** document.

Phase 2 - Feasibility study

This phase considered whether effects-based standards can realistically be set in the UK context. The findings are based on;

⇒ The extent to which there is general agreement (or not) on the existence of an effect due to noise

⇒ The extent to which there is general agreement (or not) on underlying noise-exposure relationships and how reliably these can be used to set threshold indicators for effects.

⇒ The uncertainties associated with assessing separate effects and aggregating them into an overall impact on health

⇒ The role of other factors apart from noise exposure level in setting meaningful, practical, and attainable noise criteria.

3 NOISE AND HEALTH - THE SCIENTIFIC EVIDENCE

3.1 DEFINING IMPACTS ON HEALTH

"Life is not just being alive, but being well" (MARTIAL AD 40- AD 103: Epigrammata)

Good health is very important to overall quality of life. But what is good health? The World Health Organisation has defined health as follows:

> *"a state of complete physical and mental and social well-being and not merely the absence of disease or infirmity"* (WHO 68)

and explained the requirements of a good healthy environment:

> *"Good health and well being require a clean and harmonious environment in which physical, physiological, social and aesthetic factors are all given their due importance. The environment should be regarded as a resource for improving living conditions and increasing well being"* (WHO 90)

The WHO definition of health does not define what is meant by 'well being'. But how do we measure the well being of an individual or population? Morrell measures health quality statistically as follows;

> *"People are healthy until they are deemed not to be so. The relative health can be determined by comparative population measures of mortality, morbidity and impairment"* (MORELL 97),

Many people might consider the concept of good health to be more dependent on individual expectations than this. The Dutch Health Council proposed yet another definition of good health which could be applied to set 'norms' in relation to both individual and public health and which was not solely based on purely objective measures:

> *"Health is a dynamic condition of the organism which functions properly and mentally according to the individual's age, sex and general conditions of the population to which the individual belongs, and the current state of science and technology and the related objectives of health care and public health, the beliefs and the cultural patterns of society"*
> (NETHERLANDS 97)

It is clear that definitions of good health vary. Any individual's state of health can vary up or down a scale defined by expectations and cultural needs. Expectations and needs vary and depend on the situation, circumstances and belief systems within the society within which they are formed. Relative health impacts can be only be determined by comparing objective measures against expectations and needs for any particular situation.

In the field of noise and health, policy makers are often faced with considerable uncertainty. First, there is uncertainty as to the direct magnitude of any objectively measurable effects of

health. Second, there is even confusion in the literature about the way these effects are defined. This makes the task of balancing the costs of noise control action against the likely outcome in terms of health effects problematical.

The main emphasis of current noise standards and regulations is annoyance. This is probably because the most immediate consequence of unwanted environmental noise exposure is complaints. Many airports in particular have a long standing history of persistent noise complaints from a significant minority of noise exposed residents. Individuals are perfectly competent to decide whether they are 'annoyed' or not, or whether they believe their sleep has been disturbed. For this reason, annoyance has formed a natural and immediate topic for research over many years. In the sense that annoyance and perceived sleep disturbance can interfere with perceived 'quality of life', then these effects are already included in the broadest definitions of health effects.

On the other hand, annoyance and perceived sleep disturbance are in any sense of the term, much less 'serious' health effects than cardiovascular or mental disorders would be, if they occurred. The problem here is that individuals generally have no way of knowing whether noise has had any effect on their general health or not, as this can only be determined by observations of increased morbidity in the general population. To the extent that proven effects on cardiovascular or mental health would be likely to be perceived as much more 'serious' impacts on general health than mere annoyance or perceived sleep disturbance, then any greater emphasis on these topics for the future must be encouraged. A statement that x or y percent of the population would be likely to suffer from some life threatening disease as a result of stress caused by environmental noise would form a much more transparent basis for any future policy decisions than current generalities about the relative likelihood of annoyance underlying many existing standards and regulations.

It is important to understand that individuals cannot make reliable judgements about the precise causes of any 'serious' adverse health effects that might otherwise be attributable to excessive noise because, if such effects exist, they appear to be quite weak and might only be contributory to other causal factors. It is effectively impossible to resolve the complex mix of separate potential risk factors and their combination in any individual case. For this reason, it is necessary to talk about increased or decreased risk rather than precise cause, and only large scale studies looking at the progressing health status of groups of individuals under changing environmental conditions can discover the truth about these matters. Even in the case of sleep disturbance, which might otherwise seem to be an obvious and easily reported effect, it turns out that individuals are generally not very good at being able to report precisely what happened on a previous night. While this is not surprising in the sense that people cannot be expected to recall what happened when they were mostly asleep, it is not helpful in being able to obtain definitive measures of the relative magnitudes and importances of these effects. People's perceptions of the relative magnitudes of these effects might be just as important as their actual magnitudes. Given the present state of scientific knowledge, and subject to future research, the possible adverse health effects of environmental noise might best be considered as an issue of public perception rather more than as an issue involving a direct and proven health risk.

In essence, to judge an impact on health, policy makers will need to know;

- potential effects and their relative dependencies on different types of exposure.

- levels of exposure at which these effects become significant

- different ways in which the most significant effects can be linked, combined or prioritised when judging an overall impact on health

3.2 POTENTIAL EFFECTS OF NOISE ON HEALTH

Shaw (SHAW 96) emphasises the importance of a thorough understanding of all effects of noise on people to assist in bringing community noise exposure under control in the most consistent and effective way. These effects include; psycho-social effects such as annoyance and other subjective assessments of general well-being and quality of life; effects on mental health; effects on sleep which can be both psychological and physical effects; effects on physical health such as hearing loss; and stress-related health effects which can be psychological, behavioural, somatic and physical. Possible indicators of these different effects cover a very broad range.

Annoyance

Annoyance has been defined as *"a feeling of displeasure evoked by a noise"* (WHO 80) and *"any feeling of resentment, displeasure, discomfort and irritation occurring when a noise intrudes into someone's thoughts and moods or interferes with activity"*. It is the most common and most researched effect of noise on people and can often be related to the potentially disruptive effects of intrusive noise on a broad range of activities, although people can be annoyed by noise simply because they feel it to be inappropriate to the situation in which it is heard. It can only be measured by a subjective report, although techniques have been investigated based on observing behaviour assumed to be related to annoyance. Noise annoyance is simple in concept, but since it can only be defined subjectively, comparative studies are often defeated to some extent by the problems of comparing annoyance scales using different verbal or numeric descriptors. The extent of noise annoyance, however described or reported, is clearly influenced by numerous non-acoustic factors such as personal, attitudinal, and situational factors in addition to the amount of noise per se.

Noise annoyance is usually attributed to a specific source of noise, yet the underlying causal mechanisms are not always clear (PORTER 1997). Research studies can often be surprisingly vague in terms of whether specific or general effects are being described. For example, reported annoyance to a specific noise source can often considerably exceed aggregate or total annoyance to the overall noise environment. Many researchers have concentrated on the role of specific interferences with speech, communication, sleep, concentration, or task performance in mediating reported annoyance, but the underlying relationships found vary from one study to another. Figure 1 shows one of many possible interpretations of the various underlying relationships between noise and reported annoyance showing both direct and indirect routes from stimulus to effect.

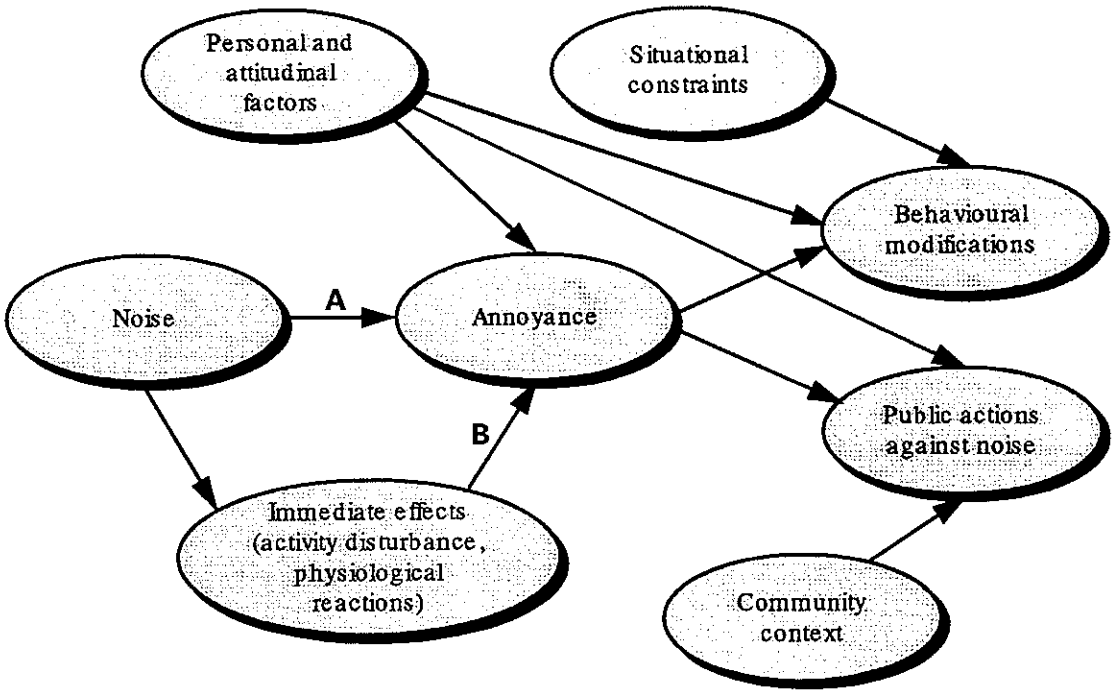

Figure 1: Noise annoyance in a community setting (from NELSON 87)

Speech interference

Human society depends on communication by speech, which is subject to masking by noise. The precise degree of interference with speech communication can be measured either subjectively by using rating scales, or objectively by measuring the percentage of words or sentences correctly understood (true speech intelligibility measures). Physical measures of so-called speech intelligibility such as the Speech Transmission Index and the Articulation Index are only proxies for direct measurement using subjective reports or proper behavioural tests, and can give erroneous results.

Environmental noise, especially varying and intermittent noise, can interfere with many activities involving speech. The extent to which any particular degree of speech interference can be overcome or contribute to stress in different situations is not well understood.

Performance - concentration and task interference

Noise can contribute to increased arousal; can require changes of mental strategy; can impair social performance; can distract attention from relevant social cues; can mask wanted signals in tasks involving auditory cues; and can contribute to what has been described as unwanted aversive changes in affective state. Interference of this type can contribute to the creation of less desirable living environments and might therefore lead to increased annoyance and stress or to a decreased state of well-being or general health.

Mental Health

A variety of mental health effects due to noise have been suggested by research. Indicators which have been studied in the past include mental hospital admission rates, headaches, susceptibility to minor accidents, and increased reliance on sedative and sleeping pills.

Hearing loss

Noise can contribute to both temporary and permanent hearing loss, although current evidence suggests that the risks at the typical exposure levels associated with environmental noise are very low. Noise induced hearing loss often occurs at higher frequencies first, at around 4000 Hz. Hearing damage can then extend to lower frequencies and become relatively more severe after increasing exposure at higher levels. Temporary hearing loss after short term exposure may be associated with permanent hearing loss even though the physiological mechanisms may be quite different. Noise induced hearing loss can directly contribute to increased stress and annoyance, particularly in respect of speech communication and tasks requiring auditory cues. There are of course many other potential or contributory causes of hearing loss in any particular case including illness, ototoxic drugs, hereditary factors and inflammation of the middle ear.

Noise induced stress related effects

As the Dutch Health Council recognised (NETHERLANDS 97), individual reactions to a stressor can be of a psychological, behavioural or somatic nature. It is not clear precisely what is meant by the concept of stress in this situation. Not all effects of noise exposure are necessarily negative. It is clear that a certain amount of noise can contribute to beneficial arousal, and that individuals differ in the their ability to adapt. Increased arousal can assist with task motivation and thereby improve performance, depending on the individual concerned. On the other hand, excessive stress is by definition 'excessive' and there are a number of possible stress-related adverse effects of excessive environmental noise reported in the literature. Psychological effects concern feelings of fear, depression, frustration, irritation, anger, helplessness, sorrow and disappointment. Examples of behavioural reactions to a stressor are social isolation, aggression, and resort to excessive use of alcohol, tobacco, drugs or food. Psychological and behavioural stress could have direct or indirect effects on physiological processes in the body. In the absence of any more definitive results, many studies have implicitly assumed that noise could be considered as an unspecified stressor leading to over-stimulation of the central nervous and endocrine systems. Potential indicators of health impact due to stress-related effects and appearing in the literature include changes in blood pressure, abnormalities in the electrocardiogram, rates of diagnosing clinical hypertension, occurrence rates of ischaemic heart disease and other cardiovascular disorders, biochemical effects, changes in the immune system, and effects on the unborn child such as birthweight effects and incidence rates for various congenital defects.

Sleep disturbance

Sleep patterns vary considerably between different individuals and sleep disturbance can arise from a large number of different causes. Disturbance can be measured subjectively using morning after questionnaires, or objectively, using a wide range of physiological indicators. The problem with objective measurements using instruments is that they can be intrusive, particularly when used in the laboratory, and there is often a significant difference between results obtained in sleep laboratories and in own-home experiments. Laboratory studies can be extremely well controlled, particularly in terms of the stimuli used, but on the other hand, it may take some considerable time for subjects to get used to the laboratory. Field studies are difficult in terms of instrumentation, and might not be at all well controlled in terms of the pattern of stimuli that actually occur on instrumented nights. An additional problem is that the clinical or social significance of any particular increment of sleep disturbance associated with additional noise events is not at all clear.

3.3 ACTUAL EFFECTS ON NOISE ON HEALTH

A considerable amount of research has been carried out to attempt to relate noise dose to the various potential or hypothesised effects. Much of this work has merely looked for statistical associations between indicators of noise exposure and indicators of noise effect, but of course, statistical association on its own does not in any sense 'prove' cause and effect. The main problem here is that, if there are any real effects of environmental noise on health (other than 'simple' effects such as annoyance, sleep disturbance, and interference with speech and task performance), then they are likely to be quite complex and associated with more than one 'causal' factor. For example, since it is well known that different individuals respond differently to various kinds of stress, then there are likely to be a whole range of individual differences in terms of health effects of noise, very few of can ever hope to be properly controlled in any feasible research study design. Potential confounding factors and co-related variables include genetic pre-dispositions to particular health effects, individual diet and lifestyle, adopted coping strategies (the extent to which individuals might have adapted their lifestyle to accommodate otherwise unacceptable environmental stress), and various possible self-selection biases. It is possible that, on average, people who are long term resident in higher environmental noise areas might be somehow different from people who are long term resident in quieter areas as a result of having different priorities when making employment and housing choices over many years. Cross-sectional epidemiological studies cannot be expected to be able to unravel all these possible relationships, some of which might even be hypothesised to operate in different directions depending on the other circumstances present. Longitudinal studies are in theory capable of controlling for individual differences to a much greater extent, but outcomes will still depend on how patterns of noise exposure change over several years in relation to other social, economic and political changes that might occur.

On the other hand, just because research has not definitely 'proved' any causal linkage between environmental noise and long term adverse health effects, this does not mean that such linkages do not exist. It remains inherently plausible that excessive noise might contribute to long term adverse health effects, and because of this the whole area is increasingly becoming a matter of public concern.

Table 2 summarises the findings of two previous review articles, in terms of the perceived strength of available evidence in support of particular noise and health linkages. Of course, each of these findings merely represent the consensus view of the different panels of experts available at the time and are subject to modification and change as new research results become available in the future. The main findings of the primary research have shown that the following conclusions can be made about the actual existence of effects of noise on health:

- Environmental noise exposure definitely leads to reported noise annoyance in representative populations.
- Reported noise annoyance increases with noise exposure.
- Reported noise annoyance varies in different situations and in different contexts.

- Environmental noise causes other effects such as speech interference, performance interference and sleep disturbance. These effects vary depending on situation and context.
- Although speech interference can be explained by direct background noise masking, the extent to which any particular degree of speech interference can be overcome or contributes to stress in different situations is less clear.
- Sleep disturbance caused by noise is a real phenomenon, but there is considerable evidence that residents can habituate to noise and there is some doubt as to the real long term consequences of any particular degree of noise induced disturbance. It is unclear how much sleep loss is actually required before being considered a health effect but excessive interference with sleep does seem to compromise positive mental well-being.
- There is some weak evidence that environmental noise exposure may contribute to non-auditory health effects such as cardio-vascular disease.
- The evidence for real effects contributing to increased morbidity such as cardiovascular effects is not convincing at this time, although it seems scientifically plausible that a minority of the population exposed at the highest noise levels might be susceptible to some increased risk.
- Much of the evidence in support of these non-auditory health effects is based on extrapolation from laboratory studies of occupational exposure at much higher noise levels. Such extrapolation is not necessarily valid.
- There is less convincing evidence of non-auditory health effects based on direct field studies of environmental noise exposure. It is possible that such effects exist but might be very difficult to detect statistically. There are serious methodological difficulties involved in being able to carry out definitive research.
- The available literature on this topic is contradictory. In general, it is only the most poorly designed and executed results which show significant effects. Significant effects amongst the most susceptible members of the population could remain scientifically plausible, even if they are as yet unproven.

Table 2: Strength of evidence for a particular effect as judged in earlier reviews

Effect	Strength of evidence
Annoyance	Sufficient[*1] Sufficient[*2] Sufficient[*5]
Psychiatric disorders	Inconclusive[*1] Limited[*2] Inconclusive[*3] Inconclusive[*5] Weak[*6] Suggestive but inconsistent[*7]
Performance	Limited[*2] Task dependent[*5]
performance by school children	Sufficient[*1] Sufficient[*2]
Sleep	
changes to sleep pattern	Sufficient[*2] Sufficient[*7]
onset/latency	Sufficient[*1]
waking during the night	Sufficient[*1] Sufficient[*2]
waking prematurely in the morning	Sufficient[*1] Sufficient[*3]
changes to sleep stages	Sufficient[*2]
sleep loss	Sufficient[*7]
subjective reports of sleep quality	Sufficient[*1] Sufficient[*2] Sufficient[*3]
mood next day	Sufficient[*1] Sufficient[*2]
sleepiness and performance next day	Inconclusive[*1] Limited[*2]
heart rate	Sufficient[*2]
hormones	Limited[*2]
immune system	Inadequate[*2]
Hearing loss	Sufficient[*2] Sufficient[*5]
Stress related health effects	
hypertension	Inconclusive[*1] Sufficient[*2] Inconclusive[*3]
ischaemic heart disease	Sufficient[*1] Sufficient[*2]
forms of cardiovascular disease	Inconclusive[*3] Inconclusive[*5] Limited[*6]
biochemical effects	Limited[*2]
immune effects	Limited[*2] Inconclusive[*6]
birthweight	Inconclusive[*1] Limited[*2] Inconclusive[*3] Inconclusive[*7]
congenital	Lack[*2] Inadequate[*5]

Key: source and classifications:

[*1] (IEH 97),
sufficient : sufficient evidence for a causal association between noise exposure and the health end point
inconclusive: evidence for a causal link between noise exposure and the health end point is inconclusive

[*2] (NETHERLANDS 97)
Sufficient: a relationship has been observed between noise exposure and a specific health effect, chance, bias and confounding factors can be ruled out with reasonable confidence
Limited: an association has been observed between noise exposure and a specific health effect, chance, bias and confounding factors cannot be ruled out with reasonable confidence
Inadequate: the available studies are of insufficient quality, lack the consistency or statistical power to permit a conclusion regarding the presence of absence of a causal relationship.
Lack: several adequate studies are mutually consistent in not showing a positive association between exposure and health effect

[*4] (BERGLUND 96) [*5](SHAW 96) [*6](THOMPSON 97)
Classifications inferred from text

3.4 AT WHAT NOISE THRESHOLD LEVEL CAN NOISE AFFECT HEALTH ?

How strong is the research evidence that noise effects follow any particular relationship with the degree of noise exposure? Both field and laboratory data has been used to derive a number of standard dose-effect curves showing very little response at around 40 LDN up to around 100% highly annoyed at around 90 LDN. Figure 2 shows the Schultz curve and its later update relating percent highly annoyed to day-night average sound level (FIDELL, 91). Similar curves have been developed for other effects such as activity and sleep disturbance (see MIEDEMA 92 and PORTER 97). These curves are not summarised in this report. There are of course numerous methodological problems present when attempting to combine the results of a number of different primary studies into an overall meta-analysis and the precise shape of the curves should not therefore be taken too literally.

All curves follow the same generic shape regardless of the particular effect being considered. Due to the scatter of individual data points above and below the curves, the precise shape is often determined more by the method of statistical analysis used than by the actual data. In principle however, noise effects are, or can be assumed to be, low or negligible at low noise levels. At increasing noise levels the effects start to increase slowly at first and then more rapidly. Finally the upper end of the effects scale flattens out at 100%. It is meaningless to consider further increases in the effects of noise above this point where 100% of the population are affected or where individuals are 100% affected. This is shown in figure 3. Whether the shape of the generic S-curve really follows from the available data (given the general statistical uncertainty in this area), or whether it is merely a plausible theoretical construct that happens to fit the data as well (or as badly) as any other theoretical construct is a matter for conjecture.

On the assumption that the lower asymptote of the curves represent threshold noise exposure values below which effects are infrequent or unlikely, it is possible to derive the guideline values set out in Table 3. For effects other than percent highly annoyed, activity interference and sleep disturbance, the precise shape of the corresponding S-curves is extremely uncertain, even if these hypothetical effects really exist, particularly at the sort of levels typical of environmental or residential exposure. Even for the percentage highly annoyed, it is well known that residents can register strong objections to certain types of noise such as that generated by inconsiderate neighbours even where the noise levels are quite low in absolute terms.

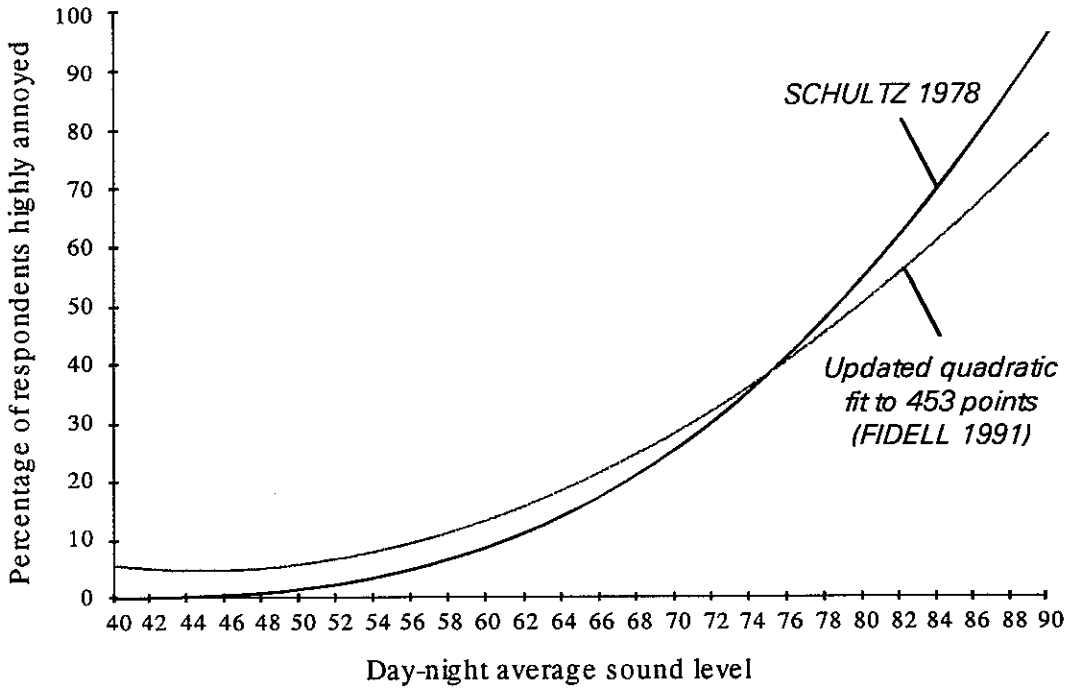

Figure 2: Percentage highly annoyed versus noise level (from FIDELL 91)

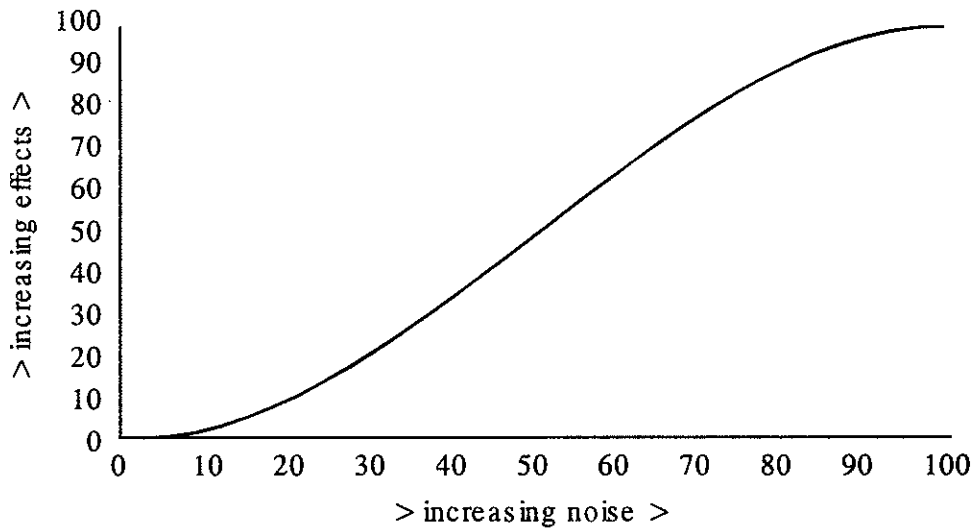

Figure 3: Generic curve for noise effects versus noise level

Table 3: Guideline threshold noise exposure values below which reviews report that an effect is unlikely to be observed

Effect	Guideline threshold value (dB(A))
Annoyance	40 ($L_{Aeq,24h}$: transportation noise) [*1] 42 (L_{dn}: outdoors) [*2] 55 (dB L_{Aeq}: outdoors, few seriously annoyed below this value)
speech communication	45-55 (dB L_{Aeq} :for elderly or impaired)[*4] 55-65 (dB L_{aeq}) [*4]
Sleep	30 (dB L_{amax} - for continuous noise to avoid serious effects) [*4] 45 (dB L_{amax} - for low background and non-continuous noise) [*4]
waking during the night	60 (SEL indoors) [*1] 60 (SEL indoors) [*2] 60 (dB L_{Amax})[*4]
changes to sleep stages	35 (SEL indoors) [*2] 40-45 (dB L_{amax}) [*4]
subjective reports of sleep quality	40 ($L_{Aeq, night}$) [*1] 40 ($L_{Aeq, night}$:outdoors)[*2]
mood next day	60 ($L_{Aeq, night}$) [*1] 60 ($L_{Aeq, night}$:outdoors)[*2]
heart rate	40 (SEL indoors) [*2] 45 (dB L_{Amax})[*4]
Stress related health effects	
general cardiovascular effects	65-75 (dB L_{Aeq})[*4]
hypertension	70 ($L_{Aeq,\ 06\text{-}22h}$:outdoors for road and aircraft traffic noise in living environment) [*2]
ischaemic heart disease	70 ($L_{Aeq,}$:outdoors) [*1] 70 ($L_{Aeq,\ 06\text{-}22h}$:outdoors for road and aircraft traffic noise in living environment) [*2]
Hearing loss	70 ($L_{Aeq,}$:indoors for living and recreational environment) [*1] 65-75 (dB L_{Aeq}: "negligible" risk for hearing loss for 8 hour exposure and 40 years age group) [*4]
Performance	55-65 (dB L_{Aeq}: for deteriorated reading acquisition in school children, people learning languages and the elderly) [*4]
performance by school children	65 ($L_{Aeq, school}$:outdoors) [*1] 70 ($L_{Aeq, school}$:outdoors) [*2]

Key:

*1 (IEH 97), guideline value is the value above which an observable effects might be expected

*2 (NETHERLANDS 97), guideline value is the value of the lowest exposure at which on average an effect has been observed in epidemiological studies

*3 (MORREL 97)

*4 (BERGLUND 96), value is based on (BERGLUND 95) and indicates the value above which an effect is observed

3.5 LINKING THE ACTUAL EFFECTS OF NOISE TO AN OVERALL IMPACT ON HEALTH

Where reliable exposure response curves exist, and there are of course some doubts on this score in relation to certain effects, we might then assume a direct relationship between the effect of interest and the associated community impact as follows:

exposure $\Rightarrow$ effect$\Rightarrow$ impact

The actual situation is rather more complex. Exposure can lead to more than one effect, and community impacts depend on multiple effects as follows:

exposure $\Rightarrow$ effect $\Downarrow$

exposure $\Rightarrow$ effect $\Rightarrow$ impact

exposure $\Rightarrow$ effect $\Uparrow$

There is no agreed method to combine everything into an overall response, even if this were meaningful when taken out of the context of the many and varied social and economic factors that often have much greater health impacts. Most reviewers avoid this problem completely by considering each effect separately, but this is not by any means a satisfactory solution. Recently, Job has set out a preliminary linked model reproduced as Figure 4 (JOB 96). It is debatable whether this really is a comprehensive model or merely a graphical representation of the various inter-relationships that need to be taken into account, but at least it shows that researchers are beginning to tackle some of these essentially quite difficult problems.

Thompson has supported Job's approach by suggesting that effect modifiers could be viewed, not as confounders, but as intervening factors in the causal chain either re-inforcing or diminishing the original stress response (THOMPSON 96). She recommends that future research should tease out those factors which are 'necessary' in the causal chain and which offer evidence that noise exposure precedes the given physiological changes. It is our view that future research which is not specifically addressed to carefully developed and biologically plausible causative hypotheses is unlikely to be able to unravel any of these complex relationships to any useful extent whatsoever. Far too many studies in this general area have merely assumed that some relationship between noise exposure and the health effect under investigation 'exists' and that mere statistical association will be sufficient for

the findings of the study to be useful when deciding policy, but there is no evidence that studies of this type can be of any assistance at all.

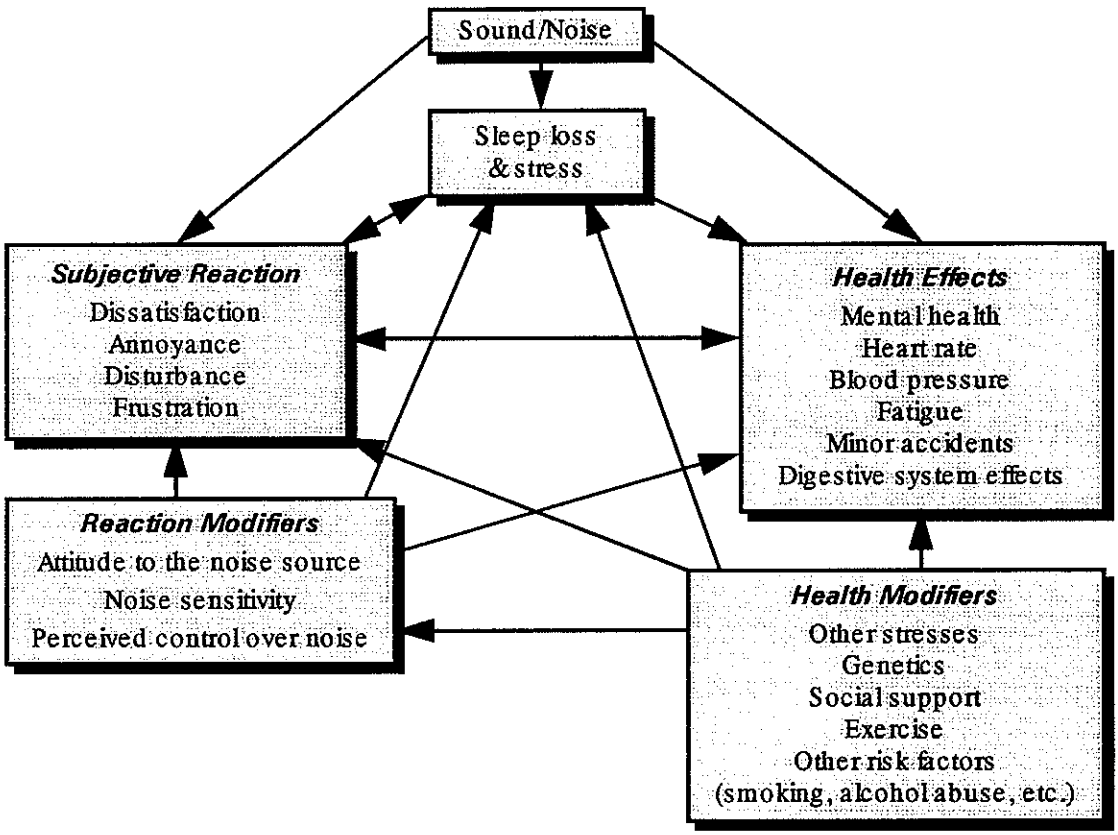

Figure 4: A model of the causal connections between noise, community reaction, modifiers and health effects (from JOB 97b)

Table 4 : Vulnerable, susceptible or sensitive groups for each effect (as discussed in the literature)

Effect	Susceptible or sensitive groups
Annoyance	self-reported noise-sensitive individuals[*1] noise sensitive people, people with fear of certain sources, those feeling they have no control over the situation have an increased risk of severe annoyance[*2] those who indicate fear of aircraft crashes, those concerned with health effects of noise, those who report interference with activities, self-reported noise sensitive individuals[*3]
general well-being	people annoyed by noise in the work place show an increased post-work irritability which might affect their well-being[*2] Those with a negative attitude towards noise may be more likely to suffer health effects[*5]
speech communication	elderly and hearing impaired
Sleep	ill people, older people, people with sleeping difficulties[*2] elderly people, shift workers, those with physical or mental disorders people with sleeping difficulties[*4] Shift workers[*5]
waking during the night	sensitive groups e.g. anxious/depressed[*1] older people
Stress related health effects	
general cardiovascular effects	family history of cardio-vascular disease[*5]
hypertension	family history of hypertension[*1] people highly annoyed by low levels of road traffic noise[*2] people with noise-induced sleep disturbance[*2]
ischaemic heart disease	men exposed to high levels of traffic noise and occupational noise[*2] people with noise-induced sleep disturbance[*2]
Hearing loss	effects on the unborn and young children[*2]
Performance	
performance by school children	pupils with learning difficulties, hearing impairment, English as a second language.[*1]

Key:

*1 (IEH 97)

*2 (NETHERLANDS 97)

*3 (MORREL 97)

*4 (BERGLUND 96),

*5 (JOB 96)

Understanding the role of effect modifiers in contributing to outcome variables is important when attempting to assess likely health outcomes after long term exposure to any particular noise environment. Two areas in Job's model relate to reaction modifiers including those relating to individual or group sensitivity (vulnerable or susceptible persons). Various reviewers have suggested ways of identifying vulnerable groups as listed in table 4, but some of the entries reported here do not stand up to close examination. It would be surprising if 'self-reported noise sensitive individuals' did not report higher noise annoyance in noise attitude surveys, but this does not necessarily mean that those same individuals are actually any more significantly affected by the noise. In the absence of any biologically plausible theory as to how noise might actually contribute to hypertension, there is no a priori reason why the class of people with a 'family history of hypertension' should actually be any more sensitive to noise induced hypertension than anyone else. It is equally plausible that people with a family history of hypertension or self-reported noise sensitive individuals might somehow be predisposed towards avoiding higher noise levels that others accept and thereby suffer less health effects as a consequence.

What would be most relevant here would be independently observable variables that might actually modify the strength of the effect being addressed. For example, people with a previous history of ischaemic heart disease or hypertension might be more or less susceptible to future episodes of cardiac ischaemia in the presence of noise than they would otherwise have been. This then becomes a testable hypothesis and is potentially useful in terms of planning future research. To merely ask people how annoyed they are and then relate this to self-reported noise sensitivity is essentially tautologous and not particularly useful for anything other than strictly academic purposes. Other examples might be to compare exposure response relationships between people with high fat and low fat diets, or between people who are measurably more or less reactive to sudden impulsive noise.

Ludlow and Flindell have pointed out that identifying susceptible individuals by means of some independent measure in advance could significantly increase the statistical power of any future research studies in this area (LUDLOW 97). The basic problem which must be overcome for any worthwhile progress to be made is the strong possibility that true effects, if they exist, will be completely swamped by the general statistical uncertainty caused by a combination of the effects being weak, of their affecting only a minority of the population, and of the large number of potential confounding and co-related variables involved. Prior identification of susceptible individuals could go a long way to overcoming some of these limitations. The traditional approach has been to merely consider particular groups as being somehow 'vulnerable' such as old people and young children, even though there is no real evidence in support. It is unlikely that this traditional approach will be at all helpful.

There are further difficulties caused by combinations of noise exposure from more than one noise source. This particularly arises in the case of road traffic noise, which is often present at the same time as other sources. Differences in individual noise exposure attributable to different occupations and life-style are unlikely to be very well represented by measurements of environmental noise taken outside houses. There have been a number of attempts to develop models of combined noise, most recently reviewed by Gjestland (GJESTLAND, 97). There is no consensus at the present time at least in part because no researcher has yet developed a model which can be successfully generalised across to other situations.

Finally, Berglund and others (BERGLUND 95) have suggested that certain essentially mild or trivial noise effects found after short term exposure in laboratory type studies might translate to more significant or serious effects after long term exposure. While this is a plausible suggestion, there is no particular reason to be believe it to be true and there is a great danger of it being used to justify what might otherwise be an unjustifiably precautionary approach. The problem here is perhaps best explained by example. It is well known that short term exposure to relatively high noise levels in laboratory situations can contribute to a number of physiological responses, such as transient elevations in blood pressure, heart rate and certain biochemical indicators. The translation hypothesis then goes on to associate these transient physiological changes with more permanent changes such as hypertension and altered endocrine function, and the case for a precautionary approach is thereby 'proved'. This argument is specious as there are many indications that these same transient physiological responses can be beneficial, particularly when associated with exercise.

In conclusion, it must be recognised that the human organism is extremely complex and it is therefore not surprising that that there are great difficulties in expressing cause-effect relationships in simple terms, particularly when it is remembered that the effects of noise are all indirect in the sense that they represent the way that the body reacts or responds to noise stimuli. There are no direct effects of community and environmental noise on the tissues of the body because the levels of energy involved are far too small.

4 PRACTICAL NOISE CRITERIA

4.1 BALANCING THE DESIRABLE AND AFFORDABLE

In general, practical noise targets or criteria are a compromise between the desirable and affordable. It is desirable for the noise environment to be as quiet as possible, but human activity itself generates sound. In setting targets we need to consider how much noise should be regarded as an acceptable by product of normal living.

The most recent draft revision of ISO 1996 part 0 recognises three and only three possible outcomes of any noise assessment ranging from acceptable to unacceptable;

Outcome class A: zero or negative noise impact where no action is required.
Outcome class B: intermediate noise impact in the range between zero and unacceptable outcome.
Outcome class C: completely unacceptable noise impact.

The division between these outcome classes can be illustrated by considering the effect consequences of increasing noise level. Let us return to our generic S curve that represents increasing noise effects against increasing noise levels (figure 5). We will consider a single effect for now so that our explanation is not confused with trying to 'total' all the effects.

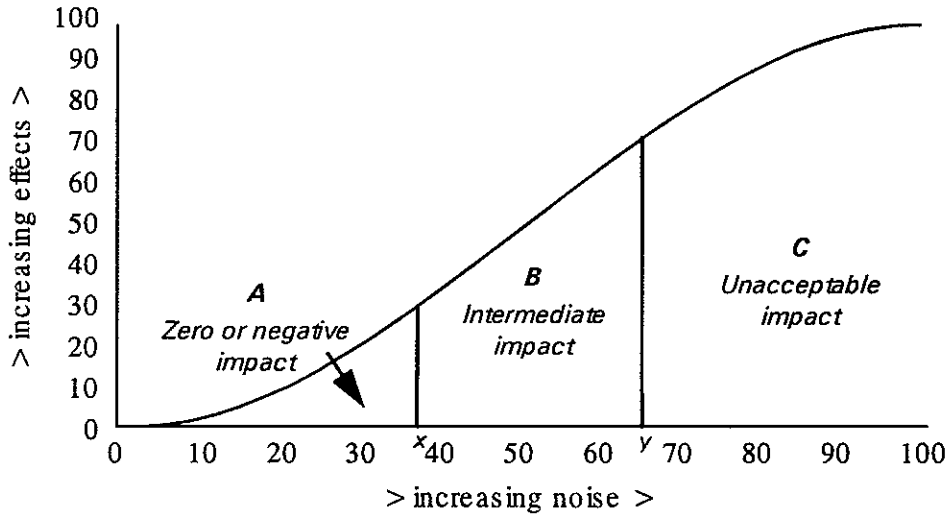

Figure 5: Generic curve for noise effects versus noise exposure showing three assessment outcomes

The generic curve follows the same general shape irrespective of the particular effect being considered. At low noise levels (outcome class A) there are generally low or negligible noise effects, either in terms of the strength of the effect or in terms of the percentage of the population affected. At increasing noise levels the strength of the effect or the percentage of the population affected also increases (outcome class B). However, these effects are not such as to be over-riding in any assessment. At some increasing noise level, the magnitude of effects may become unacceptable (outcome class C) in which case noise control action becomes imperative regardless of any costs or inconvenience incurred.

Where existing noise limits are based on scientific evidence, they are necessarily indicative of a threshold X dividing outcome classes A and B, since the definition of a threshold of unacceptability (threshold Y, dividing outcome classes B and C) is essentially a matter of social, economic and political interpretation. Of course, the avoidance of all noise impact (noise levels below threshold X) would be a commendable aim, but this is rarely achievable without unacceptable costs or inconvenience in other areas. There is a tendency within parts of the scientific community at the present time to mis-represent scientific data which actually indicates the position of threshold X on the noise level scale as indicating the position of threshold Y, and this is a mistake.

4.2 EXISTING METHODS USED TO ASSESS ENVIRONMENTAL NOISE

As part of the review work the noise criteria adopted in the UK and some of other EU countries have been examined. Full details are reported in Appendix II by country and noise source.

The short timescale allowed for this project imposed some limitations on the amount of information which it was possible to collect and on the level of comparative analysis which it was possible to undertake.. It is recommended that additional resources should be directed towards the full analysis and completion of this review, to be carried out as a separate study. A comprehensive programme of verification and wider dissemination of the information collected could be of considerable value. It should include updated tables as given in the Porter and Gottlob papers (PORTER 95, GOTTLOB 95). For this work, a few brief conclusions are made below in the context of this project.

- Exposure limits vary for different receptor locations and types of source

- Most adopted limits appear to refer to annoyance. The threshold values given are in general larger than those based on the scientific evidence alone.

- The limits are generally based on measurements, although prediction is used mainly in addition to measurements.

- The basis of the limits and procedures can be broken down into several groups:

    1. Those based on the results of primary research (e.g. The Swiss limits for general abatement of noise from road, rail and industrial noise).

    2. Those directed by social, economic, and political considerations (e.g. the general noise limits in Italy).

    3. Those that use as a base the limits set in other countries (e.g. airport noise in Italy)

    4. Those that are perhaps almost arbitrary in terms of their derivation or depend on historical origins (e.g. qualification for noise insulation from railway noise in the UK).

- Some research is planned but there is an indication of the importance of EU activities on formulating an "EU Noise Policy" in planning future research.

These findings confirm that noise targets, criteria or limits are not usually based on assumed health effects (other than annoyance or sleep disturbance). Existing standards and regulations usually take the results of primary research into account to some extent, but social, economic, and political considerations are often at least as important as suggested in the last section. Furthermore, this review has revealed that the aetiology of many existing