THE MEASUREMENT AND PREDICTION
OF AMBIENT ENVIRONMENTAL CONDITIONS
IN URBAN AREAS

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A Thesis submitted in partial fulfilment
of the degree of

DOCTOR OF PHILOSOPHY

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AUGUST, 1979

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SUMMARY

The thesis reports the development of a simple, readily applied method for mapping ambient environmental conditions in urban areas. The mapping method is based upon predictive rather than purely descriptive techniques. The use of a predictive approach involves an extension of knowledge on the causes of spatial environmental variation; theory concerning environmental measurement and prediction is also advanced where this facilitates the development of the mapping methodology.

The chief operational role of the proposed methodology is to provide spatial environmental information for use in policy making contexts - for example at the strategic level of local authority planning - where policy issues with significant environmental content are considered. The influences of both theoretical and operational issues in the development of a valid and useful methodology are examined.

The proposed mapping methodology is founded upon the central hypothesis that the spatial pattern of urban environmental conditions is underlaid by, and may therefore be predicted from, an associated pattern in the urban fabric. The bulk of the research is concerned with an empirical case study through which the validity of this hypothesis and its application in a mapping methodology are examined. The hypothesis is articulated spatially and testably through a key concept termed the 'Typical Area Element' (TAE). This concept involves envisaging the spatial pattern in terms of grid square 'area element' zones, classified into distinct, 'typical' urban fabric categories by two parameters, land use and road network density. Since the concept as developed and tested in this research is intrinsically limited to non-localised, 'ambient' environment attributes however, the resulting TAE methodology may be generalised only to 'ambient' environmental conditions.

The empirical work was conducted in the West Midlands Metropolitan County and the TAE methodology was tested in four case studies covering ambient noise, sulphur dioxide air pollution, area appearance, and an indicator of 'aggregate environmental conditions'. In each instance the TAE methodology was validated, and empirical 'area-based spatial prediction models' based on the TAE were calibrated, and then applied as mapping methods for the case study area.

environmental planning, pollution, mapping, noise, air pollution

ACKNOWLEDGEMENTS

Many members of staff and students in JURUE and APUS have given me help and advice during the course of my research, and in these few words it is possible for me to thank individually only a handful of those to whom my deep appreciation is due.

Frank Joyce and David Johnson have from the earliest contributed constructive thoughts and comments on the development of my research. Geoff Taylor introduced me to the technical problems of noise monitoring and advised me on the conduct of the survey technique, while Ian Andrews, Chris LeFevre and Chris Robinson gave assistance in the computer analysis of the data. Nicole Mainwaring has been a source of valuable help with graphics and map design, and Elaine Kirby has had the unenviable task of typing my handwritten draft.

Above all however my deepest debt is due to Hugh Williams, my Academic Supervisor, for the energetic and rigourous scrutiny that he has consistently applied to every stage of my research; his enthusiasm and imagination have given me the greatest encouragement.

Finally I must thank Marjorie Bridle for enduring and sharing with me the seemingly endless internment that has accompanied the writing of this thesis.

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CHAPTER 1

A GENERAL REVIEW OF THE RESEARCH PROBLEM

1.0 A GENERAL INTRODUCTION TO THE RESEARCH AND THESIS

1.0.0 Overview

The thesis reports the development of a methodology for mapping ambient environmental conditions in urban areas. The principal elements of the research problem in response to which the methodology was developed are outlined in this introductory section; the remainder of the chapter is concerned with substantiating the issues behind the research problem, in order to explain the nature and conduct of the research and thereby to provide an introduction to the matters which form the content of the remainder of the thesis.

1.0.1 The Research Problem

The research is presented in this thesis under the title 'Measurement and Prediction of Ambient Environmental Conditions in Urban Areas'. This title subsumes three areas of increasingly specific interest which in the development of the research were termed the 'research area', 'research problem area', and 'research problem' respectively. The thesis is concerned with the reporting of a detailed response to the 'research problem', but at this stage a useful means of establishing a context and perspective of the research is provided by a brief statement of each of the three areas of interest:

(i) The Research Area: 'Environmental Quality as a Policy Issue in Public Administration'

This general background to the research concerns the management and control of environmental quality within the UK, and the treatment of environmental quality in policy terms within those public bodies charged with relevant administrative responsibility.

(ii) The Research Problem Area: 'Measurement and Prediction of Ambient Environmental Quality in the Planning Context'

This more restricted area of interest involves a focussing of attention upon the problems of the provision of data to facilitate environmental decision making, particularly concerning the issues of measurement and prediction, and the narrowing of the policy context to local authority planning. Through specifying the ambient environment, other environments such as the work place, domestic and other indoor environments, and also highly localised outdoor environments, are excluded from the research. The main attention in the research area is therefore on the provision of ambient or 'background' environmental information in order to aid certain policy contexts.

(iii) The Research Problem: 'Development of a Methodology for Mapping Ambient Environmental Conditions in Urban Areas'

The research problem poses the specific topic which formed the subject of the research. The research area policy context is maintained but it is seen that it is explicitly the spatial distribution of data that is of interest, as expressed in the form of maps. The term 'environmental conditions' (rather than 'quality') indicates the necessary restriction to an operational measurement of physical environmental conditions; moreover it is essentially the urban environment and scale that is to be investigated.

In responding to the research problem a number of central problem issues were encountered.

1.0.2 The Principal Problem Issues

Broadly the research was required to examine three sets of problem issues.

(i) Environmental Issues in Public Policy

It was necessary to examine the application of the mapping methodology in its role as an aid to decision making in policy contexts which have some significant environmental content. An understanding of the relationships between the methodology and its context was considered important since it was recognised that in any given study the operational policy context is crucial in determining precisely what environmental information is of interest, and in identifying the specific requirements of the data, particularly with regard to the spatial level of detail and the spatial and metric accuracy of the data. Without a specific operational case study, the research was restricted to a consideration of a generalised operational context; the nature of this context was derived from a review of the administrative responsibilities of the relevant public authorities (see section 1.1). The chief influence of the generalised operational context upon the development of the mapping methodology was in crystallising the demand for a simple, cheap, versatile, readily applied method, appropriate to the urban scale and using easily obtained input data. Attention was also directed to the importance of the issues of the spatial and metric accuracy of the data.

(ii) Problems in Environmental Measurement and Prediction

These problems, which are evident generally in environmental analysis, were examined specifically with respect to their significance in spatial analysis, and the research was dominated by the theoretical and methodological problem of developing a mapping method which, while responding to the operational demands of simplicity, versatility and parsimony, would also be capable of responding to the problems of measurement and prediction. In general the main measurement issues in spatial environmental analysis concern the choice and definition of appropriate and readily measurable environmental indicators, the method of obtaining measurements given the temporal and spatial variation in the observed conditions, and the requirement for respresentative and acceptably accurate data to be obtained through sampling. The prediction problems concern the knowledge of causal factors affecting environmental conditions, and, in this context particularly, the causes of spatial environmental variation. These issues were encountered specifically in the research, in the formulating, testing and calibrating of explicit predictive models based on hypotheses and established theory.

(iii) Issues in Mapping Environmental Conditions

These essential spatial issues lay at the heart of the research problem. The key issues were found to be the obtaining of a spatially comprehensive data coverage of the study area, the method of spatial representation (for example the use of isolines or zones), the spatial scale and accuracy of the representation method, the method for obtaining the spatial data (for example from sample measurements, or from predictions based on source locations or area types), and problems concerning aggregation. In each case it was necessary to consider the demands and constraints of both operational applicability and theoretical validity. The mapping methodology developed by this research encountered and was designed to respond to these specific issues and those more general points mentioned under headings (i) and (ii) above; the methodology itself is summarised below.

1.0.3 The Mapping Methodology

The methodology involves a predictive mapping approach based on the use of empirically-calibrated 'area-based spatial prediction models'. This approach rests on a central hypothesis which asserts that the environmental conditions of an area are related to certain characteristics of the area's urban fabric[1]; in spatial terms this leads to the view that the pattern of environmental conditions over a conurbation is underlaid by an associated pattern in the urban fabric. The key to, (and essential strength of) the mapping method lies in the validation of this hypothesis since it follows that, upon validation, the environmental pattern can then be predicted

1. Here, 'urban fabric' is understood to consist of such factors as land use, urban density, traffic density, building age and type, etc. Natural factors, such as topography, are excluded.

given a knowledge of (i) the urban fabric pattern, and (ii) the environment/urban fabric relationships.

The main purpose of the research was to apply this hypothesis to the development of the mapping method. Essentially there were three tasks: (i) to formulate and test the hypothesis, (ii) to calibrate the environment/urban fabric relationship in the form of an area-based prediction model, and (iii) to apply the model as a mapping method in a case study using urban fabric input data. These objectives were pursued empirically through a key concept termed the 'typical area element' (TAE), which provided a spatial and typological method for classifying the urban fabric, and consequently gave an empirical basis for the articulation and testing of the hypothesis and its subsequent application as a mapping method. Spatially the TAE concept involves approximating the study area to a grid square configuration of 'area element' zones; typologically, these are classified into TAE 'types' through a categorisation of two urban fabric parameters, land use and road network density.

The research involved the use of the West Midlands Metropolitan County as a case study area; sample environmental measurements were taken from the range of TAE types to test the hypothesis that a statistically significant relationship existed between different TAE types and different environmental conditions. Three environmental attributes were chosen for this study: ambient noise, sulphur dioxide air pollution, and area appearance.[1] The testing of the hypothesis - a process which encountered the problem issues in environmental measurement already mentioned - showed a significant relationship in each case. An 'aggregate environmental conditions' indicator was also discussed; in this case an ordinal aggregation method was proposed,

1. Area appearance is a composite indicator derived from an operational method for classifying the visual conditions of an area.

tested and validated.

Having validated the hypothetical basis of the mapping method, the area-based spatial prediction models were calibrated through allocating 'typical' environmental conditions to each TAE type. These models were modified in response to the demands of the operational mapping context, resulting in five categories of environmental conditions corresponding to five groups of TAE types. For each attribute a spatially comprehensive map showing the pattern of the five groups over the WMMC was then achieved from the predictions of the mapping models, using a 'base map' input of spatially comprehensive and readily obtained urban fabric data expressed in the form of TAEs.

As stated, the mapping method described above encountered and was designed to respond to problem issues from each of the three main areas summarised in section 1.0.2. The remainder of this chapter fills out the introduction to the research by describing the main problem areas in rather more detail and with closer attention to the way in which they make demands and constraints upon the development of the mapping methodology. The chapter concludes with a synopsis of the forthcoming chapters in the thesis.

1.1 ENVIRONMENTAL ISSUES IN PUBLIC POLICY

It has been stated that the object of the research was to develop a mapping methodology which might act as an aid to environmental policy making. An operational context for the application of the proposed method is therefore provided by the bodies whose tasks include making environmentally significant decisions. These bodies are principally public authorities, who may influence environmental conditions through a wide range of duties, powers, responsibilities and opportunities. Through a brief review of this policy framework the areas of interest to the research are identified within the general perspective of environmental policy as a whole.

1.1.1 General Review of Environment and Policy

The environment has become an issue in the field of public policy because it has been recognised that environmental conditions affect the general social wellbeing. In particular it is known that the environment may harm (a) the health, and (b) the welfare, of the community of individuals that it is public policy's task to safeguard. In response to this knowledge, environmental policy has been developed,

The scope and scale of environmental policy is very varied, ranging from local (District) authority pollution control within small, selected areas (for example, Smoke Control Zones and Noise Abatement Zones) to comprehensive international agreements, for example on marine pollution and the environmental impacts of air transport. In the UK, three distinct areas of policy are evident; pollution control, environmental protection and environmental planning. Within the field of pollution control, statutory duties have been highlighted by various Government reports (e.g. ROYAL COMMISSION ON ENVIRONMENTAL POLLUTION 1971, 1975, DOE 1976) and rationalised under the Control of Pollution Act 1974. Under this legislation, local (District) authorities have primary responsibilities for noise and air pollution, although the local (County) authority is required to consider these environmental attributes in the analysis of the environmental consequences of its own policies, particularly with regard to land use and transport planning (MHLG 1970). The County authority is also responsible for derelict and vacant land and the disposal of waste. Regional Water Authorities take responsibility for controlling the pollution of rivers, canals and still waters, although emissions from certain registered works into waterways, and more importantly the emission of pollution into the air, are monitored by the Alkali and Clean Air Inspectorate under the auspices of the Health and Safety Executive. In addition to these statutory duties, there are further provisions arising both from Common Law and from Statute Law (particularly the Public Health Act 1936), whereby a statutory or common law nuisance may be identified by the courst. In all cases, the offender or polluter must take the 'best practicable means' to ensure that the problem is abated. At national level, the Health and Safety Executive and the Secretary of State for the Environment have certain powers relating for example to the control of radiation conditions and the sulphur and lead content of fuels. At a still wider scale, EEC Directives are playing an increasingly important part in determining this level of policy.

Environmental protection policy is manifest in the variety of means whereby certain desireable facets of the environment may be protected from destruction or despoilation. The classical example is the 'Green Belt' policy, the principle of which extends into the designation of Areas of Outstanding Natural Beauty, and the National and Country Parks. Desirable facets of the urban environment are taken into account in the provisions now expressed in the Town and Country Planning Act 1971; these provisions allow Conservation Areas to be designated, and other features to be safeguarded through measures such as; Preservation Orders on for example buildings or trees; regulations for the preservation of Listed Buildings and Historic Monuments, and various other powers, all of which are held by the District Authority.

Environmental planning policy involves the consideration of environmental issues in the context of local authority planning decisions. The opportunity for such considerations may arise either through the local authority's own ('promotional') planning procedure, or through its statutory ('responsive') approbation of proposals from another developer. The 'promotional' opportunities are found within the current Development Planning system (MHLG 1970), and involve the Structure Plan, made at County level, and the District/Local Plans which follow the strategy of the Structure Plan (see chapter 2.2 for further details). The critical elements in these plans are, as already intimated, the land use and transportation policies. The 'responsive' opportunities result from the local authority's Development Control responsibilities. The scale of proposed developments is very varied, and the large-scale proposals, for example the proposed Vale of Belvoir Coalfield and the Windscale nuclear processing plant, have involved an elaborate procedure of environmental impact assessment, although as yet the UK, unlike the United States, has no statutory E.I.A. policy and to date none has been firmly agreed by the EEC.

The above is of necessity a brief sketch of environmental policy in the UK, and a detailed appraisal may be gained from the literature (e.g.

CULLINGWORTH 1972, McLOUGHLAN 1972, BIGHAM 1973, LEE and WOOD 1974, WOOD 1976, SOLESBURY 1974).

1.1.2 Environmental Policy in the Research Problem Area

Clearly, while the information provided by an environmental mapping methodology will have a certain amount of relevance to many of these policy contexts, its actual value as a policy and decision aid is evident only in a limited range of applications. This section makes a more detailed study of those policy areas where the research may make a positive contribution to policymaking. This is necessary at this stage since the delimitation of the relevant policy contexts affects the environmental attributes selected for study, the manner and scale of their measurement and representation, and the nature of the mapping methodology itself.

The use of maps as an aid to environmental policy making contexts has been outlined by KARPE and SCHOLZ (1976), who assert that their value lies mainly "in the transformation of very difficult and complex data into understandable and clear information. The presentation in map form is very often much more useful than in the form of numbers and tables; the maps clearly indicate areas of heavy pollution impact and areas where standards are exceeded; also the origins of pollution can be traced." The same authors cite industrial location and environmental impact analysis as important applications, and within their own study they find their methodology "a real though only partial decision aid" in the determination of Strategic Planning Policy.

A further policy-oriented use of spatial environmental data may be found in the technique of 'potential surface analysis' (ZETTER 1974, SOUTH YORKSHIRE COUNTY COUNCIL 1978a). This has been used by planning authorities as "a technique for systematically assessing the potential of an area to accommodate a particular type of development or land use" (ZETTER 1974). The technique consists of three basic stages; "identifying the factors that combine to constitute an ideal location for an activity in terms of the realisation of a set of policy aims; next, measuring the occurrance of these factors; and, lastly, mapping them as a surface" (ZETTER 1974). As such, 'potential surface analysis' may be understood as a modified and more positive version of the traditional 'sieve map' technique used in development planning to exclude given types of activity from certain categories of area. Clearly, where the "policy aims" include matters that are related to existing environmental conditions then such conditions must be included as factors to be mapped and included in the aggregate assessment described by the 'potential surface'. As a whole, the approach is essentially the same as the method developed by the EEC (AMMER 1976, SOUTH YORKSHIRE COUNTY COUNCIL 1978b) for taking environmental factors into account in regional planning. However it must be noted that the 'potential surface analysis' approach used by AMMER (1976), KARPE and SCHOLZ (1976) and SOUTH YORKSHIRE COUNTY COUNCIL (1978a) is essentially an evaluation methodology that includes decision criteria to assess spatial environmental data. By contrast the TAE methodology described in this thesis is merely a mapping method, deliberately devoid of value-based criteria, although the resulting maps might subsequently be applied in evaluation and 'potential surface analysis' applications, as stated below. The deliberate and explicit separation of the mapping and evaluation methodologies is often an advantage in a rational system of analysis.

The application of mapped data to environmental impact assessment has been studied in some detail by Catlow and Thirlwall (DOE 1977) who have proposed the following four-step procedure for an EIA:

(a) establishment of a resource inventory: description and analysis of the existing environment in each geographical area (baseline studies);

(b) assessment of the main effects of the proposed new development;

(c) assessment of the relevant impacts resulting from the interaction of the effects with the existing environment;

(d) evaluation of the impacts.

Within this procedure the critical importance of 'baseline' data is evident in the attempt to evaluate the impacts, rather than merely the effects, of a proposed development. CLARK (1976) expands the argument with the view that "baseline studies ... provide the planning officer with an understanding of the existing situation against which he will be able to assess the likely advantages and disadvantages of development proposals". It is also clear that this function is equally viable whether the developer is an external agency or the local authority itself, and thus the application of baseline maps to an environmental impact assessment may contribute to both the responsive and the promotional roles of local authority planning.

As well as the purely descriptive role implied in the 'baseline studies' approach, there is considerable interest in the extension of mapping methodology into a more comprehensive modelling exercise where the environmental pattern is predicted on the basis of generative factors. The EEC for example, stress an interest in a mapping methodology "to provide a basis for predicting future environmental conditions and trends" (SOUTH YORKSHIRE COUNTY COUNCIL 1978b). WOOD et al (1974) go further in suggesting that "the development of a working model of the pollution process within the subregion (including air, land, water and noise pollution) could be very helpful in ... providing a comprehensive basis for pollution forecasting, land use and environmental quality decision making" (WOOD et al 1974). "Such models could, in the case of noise and air pollution for example, evaluate the effects of different highway alignments or of different industrial locations. Such subregional models would also provide the basis for setting and evaluating pollution standards ... by zoning land uses. Alternatively, different arrangements of large new increments of development (e.g. regional development proposals) could be evaluated" (WOOD 1976). This comprehensive spatial approach to environmental policy is also argued in the literature by GARLAUSKAS (1975), WERCZBERGER (1975), and SOLESBURY (1974).

The earlier discussion of contemporary environmental policy indicates that the current administrative framework is not high suited to an environmentally and spatially comprehensive policy, due to the disaggregation of powers and responsibilities, and the disaggregate legislative approach to the environmental attributes and their media and causes. In general however the principle is desirable, and it is at the local authority level that the greatest potential for a variety of both descriptive and predictive environmental mapping applications is found. It is therefore appropriate for the research to focus on this operational context. Within this administrative framework of local government a number of policy issues may be identified where environmental mapping is a relevant aid to the formulation of policy; these are summarised as follows:

(a) Descriptive role for the mapping methodology

(i) In the location of problem areas (areas with high environmental stress or where standards or criteria are being exceeded) and in delineating 'priority action areas' for immediate ameliatory policy.

(ii) In the provision of a spatial basis for the allocation/distribution of recurrent ameliatory expenditure.

(iii) In the determination of spatial land use development policy, particularly in respect of sensitive (e.g. residential) and polluting (e.g. industrial) activities.

(iv) In contributing 'baseline' information for the environmental impact assessment of proposed developments, both in the responsive and promotional fields, more especially at the strategic level.

(b) Predictive role for the mapping methodology

(i) In the prediction of future spatial conditions and trends, and in forecasting future problem areas.

(ii) In the prediction of the likely impact on the intensity and pattern of environmental conditions of alternative large-scale developments (e.g. land use or transportation network changes) for use in strategic plan evaluation.

(iii) In the incorporation of environmental factors in 'potential surface analyses', thus ensuring that environmental factors are taken into account in the positive planning of conurbations or regions.

(iv) In the development of more comprehensive, dynamic and integrated environmental policy and pollution control programmes at the local authority level.

Since the research presents a method capable of providing both descriptive and predictive spatial environmental information that may facilitate these activities, it is important to examine in more detail the role, functions and operational procedure of local government in order to assess fully the operational context of the research and the concomitant demands and constraints on the methodology developed. This is achieved as part of the development of a conceptual framework for the research in chapter 2.

1.2 GENERAL PROBLEMS IN ENVIRONMENTAL MEASUREMENT AND PREDICTION

The above discussion of the policy context establishes the operational background to the research. It is now appropriate to examine the issues surrounding environmental measurement and prediction since these naturally receive the more detailed attention in the development of the mapping methodology. These problems are associated with a range of more general theoretical issues which are examined in greater depth in chapter 2.1, where they are seen to constitute the 'theoretical context' of a conceptual framework for the research. Here the issues are given a broad introductory treatment.

1.2.1 Definition

Any measurement and analysis of a concept requires that the concept be defined, and in this respect the environment presents considerable difficulties. At the most general level it is possible to state that the environment is made up of 'the sum total of the external conditions and influences that affect man's wellbeing' (Pocock 1976). This view is however so all-embracing that it is for analytical purposes useless, and in order to develop a more practical terminology it is necessary to set about classifying 'the sum total of man's external conditions and influences'. In doing so considerable taxonomic problems are encountered due to the complexity and interrelatedness of the 'conditions and influences' and man's response to them. A general 3-stage hierarchy may be established, from 'the quality of life', the most wide ranging concept, through the more restricted 'quality of the environment' to 'environmental pollution', which is a comparatively narrow sphere of 'conditions and influences'. The research is focussed upon the 'quality of the environment' concept, which excludes much of the sociological, perceptual and psychological substance of 'quality of life' issues, yet is broader than the purely objective concept of 'environmental pollution' since, as stated, both health and welfare issues are of interest. The close link between the research and the local authority context implies that a definition might be made in terms of environmental quality issues which may be affected by public policy, but such a definition is circular in the sense that the determination of policy is itself dependent upon the analytical definition of the concepts. The earlier review of policy issues provides an illustrative example of the problems involved in disaggregating, classifying and defining environment issues. A common classification is made in terms of environmental media, for example land, air and water. This is not an exhaustive classification system however, since other aspects such as noise do not fit conveniently into a particular medium and must therefore be added as separate categories. The environmental condition of a given medium may in turn require disaggregation in order to separate individual policy components, for example distinguishing recreational water quality from drinking water quality, or land dereliction from land pollution due to wastes and tipping. Other approaches involve classifying and analysing environmental conditions by source, as with the impacts (noise, air pollution and visual intrusion for example) due to traffic, or the effects of a given type of waste, or the output of a given type of industry. And throughout this disaggregation and classification procedure which is necessary for analytical and legislative purposes, there runs the confounding consideration, already referenced against WOOD et al (1974) and others, that the environment is an 'integrated phenomenon' wherein the condition of one element or attribute is functionally associated with the condition of many others such that the attributes act as a systemic whole. Thus it is evident that any attempt to define and classify individual environmental attributes is to a considerable degree an artificial (yet still very necessary) exercise.

The research was therefore faced with the difficulty of isolating definable, individual, meaningful and relevant environmental attributes to be examined in the case study approach. Furthermore it was necessary for these to embrace the range of methodological problems encountered in measurement, prediction and mapping, and to act as a comprehensive set of components in an overall view of 'environmental quality' compatible with the role, functions and legislative powers of local government (see chapter 4.1).

1.2.2 Measurement

Further to the above requirements, it is also necessary that the attributes are defined in terms of readily measurable properties. In Chapter 2.1 it is seen that this requirement leads to the use of so-called 'operational definitions'. In addition, it will be seen throughout the thesis that the ubiquitous problem with environmental measurement is the spatial and temporal variation in the observed properties, as well as the measurability of the properties themselves. Where it is only necessary to observe a small number of locations - for example the effluent from a factory or the noise level at the factory boundary - spatial variation is not important and the resources are usually available to allow for long-term monitoring which enables temporal variation to be traced and accounted for in the analysis. The research interest is explicitly spatial however and this involves a whole range of methodological problems in addition to the basic issues which were raised in the preceding section.

Essentially these problems concern the choice of an appropriate sampling technique and sampling density, and the selection of a suitable method for representing the data. Short-term sampling is important since spatial studies cannot rely on the resources for long-term large scale monitoring. The sampling technique must ensure that the measurement method is applicable to spatial studies which are attempting to reflect the representative or typical ambient condition, and consequently the choice of the location and time period of sample measurements must avoid anomalous perturbations and unrepresentative conditions. The choice of sampling density is dependent upon the spatial variability of the measured property and the desired accuracy in the data, this latter issue being associated with the spatial precision required by the policy context and the representational method, under the constraints of resource availability. The representational method may involve continuous (e.g. 'isolining') or discontinuous (e.g. 'grid square zoning') spatial techniques, and the data must be available in a form appropriate to the demands of both the representational method selected and the policy context. The whole field of spatial representation is examined further in Chapter 3.

It is common in environmental measurement to make use of indicators as a means of simplifying the measurement method and condensing information into a form most pertinent to the needs of the operational context, particularly with respect to the performance and objectives of policy. These issues are discussed further in Chapter 2.1. An associated measurement problem exists in that the measurability of many environmental aspects is problematical and the use of cardinal measurement scales is basically restricted to some of the 'hard' pollutants (e.g. noise and radioactivity). In the cases where ordinal or nominal scales are necessary, considerable restrictions are imposed upon the uses to which the data may be put.

particularly with regard to the comparison of areas, the aggregation of data over space and aggregation of different measures (as discussed in Chapter 8), and in policy applications such as evaluation.

1.2.3 Prediction[1]

The research is founded upon the assertion that environmental conditions may be predicted as well as measured, and the implication of this is that sufficient is known about the causes of the varying levels of environmental conditions for a relationship to be established between the environmental conditions and other factors which determine them. The key element in the predictive approach is the development of models which allow the relationship to be specified in formal terms. Where modelling is undertaken, both the metric properties of the data and the formal nature of the model's specification must be considered in determining the metric properties of the predictions. In addition both the validity and the accuracy of the model will control the degree of confidence which may be held in the predicted information (the theoretical issues behind the techniques of predictive modelling are discussed in further detail in Chapter 2.1).

It has already been made clear that the research incorporated a methodology fundamentally dependent upon the technique of predictive modelling. The power of predictive modelling as applied to the research problem lies in the resulting ability to obtain a spatially comprehensive data set without the need for exhaustive environmental measurement. Furthermore a means is provided for explicitly stating and testing causal theory. A fuller account of the merits of predictive modelling as a methodological response to the research problem is given in Chapter 3.

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1. Prediction should not be confused with forecasting. Here, prediction is taken to mean the process of inferring the value of a given parameter from the values of other parameters with which it is associated through a model. Forecasting involves the prognostication of parameter values for some time in the future.

1.3 SPATIAL STUDIES OF THE ENVIRONMENT

The first two sections of this chapter have outlined the most relevant issues in the research area and research problem area. Having established a general context for the research, the chapter now sets out to review the methodologies and main issues encountered in other contemporary research which has approached the general problem of environmental mapping. The purpose of this is to prepare a basis of contemporary knowledge prior to the elucidation of the research problem issues and the specific aims and objectives of the research, which is undertaken in the following section 1.4. The elucidation may thus be made with reference to contemporary approaches, allowing the key issues to be understood within the perspective of practical study contexts.

Contemporary studies may be divided into,

(i) those that have attempted to treat the problem comprehensively and which have therefore looked at a range of environmental attributes usually in association with the procedures of a planning context, and

(ii) those which have analysed the spatial pattern of a single given attribute and have dealt rather more with such substantive issues as the meeting of objectives or standards and the theoretical understanding of the environmental pattern.

From the foregoing discussions it is possible to identify a number of criteria with respect to which the contemporary studies should be examined. Essentially these are:

(a) the relationship of the study to the policy context;

(b) the choice of environmental attributes;

(c) the choice of indicators and the method of obtaining the spatial data;

(d) the method of spatial representation;

(e) the use of predictive techniques.

These are not applied systematically to the review since they are not universally relevant and in any case the intention is to provide a general discussion of the issues appropriate to this research in the context of other studies; the criteria act principally as a basis for this.

1.3.1 General Environmental Studies

Four examples of this type of study are described, covering the range of contexts in which such studies are generally undertaken. Conclusions are then drawn in relation to the above criteria.

Apart from some recent studies responding to the statutory structure planning procedure[1] the only attempt at a comprehensive analysis of environmental pattern in the UK is that undertaken by WOOD et al (1974) in the Greater Manchester sub region. Six component attributes are studied and they, together with the selected indicators and sources of data, are given in Table 1.1.

Pollutant	Indicator, and source ( ) of data
Smoke	Winter mean concentration, 1970-1 (Warren Spring Laboratory)
Sulphur dioxide	"
Road traffic, air pollution and noise	Traffic densities per zone, 1966 (GMCC)
Land Pollution	Proportion of zone occupied by spoil tips (GMCC)
River Water Quality	Quality Class (1-4) 1970 (NWRWA)
Land Water Quality	"

Table 1.1 Pollutants, indicators and sources of data in the Greater Manchester Study (Source: WOOD et al 1974)

Key: GMCC - Greater Manchester County Council

NWRWA - North West Regional Water Authority

1. See chapter 2 for an account of structure planning.

Wood relies exclusively upon data from secondary sources, and spatially this means he is forced to use the municipal authority zones as the representational units for which the spatial data on average or typical conditions are available. This method thus provides an arbitrary and irregular configuration for the display of spatial pattern. For many zones no data are available and in these cases Wood resorts to a predictive approach, the theory of which is based on a 'sub regional wastes - pollution spatial model'. Two stages are envisaged in this model: "pollution levels in each zone are ... a function of the wastes generated (within that zone)", and "the wastes discharged from each zone ... are related to zonal population, socio-economic, industrial and land use characteristics" (WOOD et al 1974). The study did not incorporate an active policy context, but the potential applications of the methodology are argued and have already been discussed in the review of environmental policy.

A similar study has been undertaken for the Ruhr sub region of West Germany by KARPE and SCHOLZ (1976). In selecting the attributes for study, an explicit distinction is made between "natural pollution" (sulphur dioxide, dust, day noise and night noise) and "socio-economic stress factors" (lack of green space, poor public transport systems and recreational facilities). Like Wood et al, the authors are able to treat only secondary data sources; in their criteria for selecting appropriate data they are more explicit about the data requirements of spatial studies, and they considered "the representativeness and relevance of pollution factors, the reliability of the measurement procedure, the spatial differentiation of pollution factors, such that only those factors were included that differentiated in the sub region" (KARPE and SCHOLZ 1976). It appears[1] that isolining was used as the representational technique, although

1. The available publication does not describe the mapping method for all attributes.

no predictive or interpolation techniques are discussed in the available publication and so it is not clear how isolines were derived. As with the study by Wood et al, a composite, aggregate pollution index is achieved, the aggregation methods of both studies being discussed in chapter 8. Although a detailed argument is not made, the authors claim to have found their mapping methodology to have aided the decision making process of the local planning context.

A more explicit connection with policy is to be found in the work of County Authorities in the UK who perform studies of the spatial pattern of environmental pattern in association with their Structure Plan Reports of Survey. Two good examples of this kind of study are given by MERSEYSIDE METROPOLITAN COUNTY COUNCIL (1976) and CHESHIRE COUNTY COUNCIL (1977). The general objectives, as described in the Merseyside study, are to investigate "the condition of the physical environment ... the characteristics and distribution of environmental pollution and the condition of the land ... also the origins and effects of pollution produced by man's activities upon the natural resources of the County, and the quality of the atmosphere", in order "to enable other bodies to develop a dialogue with the County Council about how future policies and programmes will deal with the problems. This will then allow such policies and programmes to be incorporated in the Structure Plan" (MERSEYSIDE COUNTY COUNCIL 1976). Other more direct links with policy have been proposed, for example the comparison of the noise impacts of alternative strategic transport options against the perspective of spatial 'baseline' ambient noise data (JURUE 1977, see chapter 4.3).

The Merseyside Study examines smoke, sulphur dioxide, soil contamination by metals, damaged and unused land, litter and tipping, watercourse effluent and noise. Smoke shade and sulphur dioxide maps are obtained directly from the catographic study by the Warren Spring Laboratory (1976; see Chapter 6.2 of the thesis); soil contamination is sampled in

4 sq. Km. grid units, the measurements being interpolated into isolines using the SYMAP technique (see Chapter 3). Derelict and waste land is mapped using remote sensing techniques; no mapping of noise and water quality is attempted and the analysis is therefore limited to a qualitative consideration of tabular data for these attributes.

The Cheshire study contains a similar appraisal of conditions, with the topics for study being 'ecology', derelict-land, air pollution and noise, water pollution and environmental hazard. Spatial data is provided for air pollution (smoke and sulphur dioxide) from the Warren Spring Laboratory maps as before, while a special study of these pollutants is made in the Runcorn area by the County itself and mapped using SYMAP. The same area and representational technique is used for an examination of soil contamination by heavy metals. Noise is not mapped comprehensively but over the special study are isolines of the day and night L_{eq} are predicted from standard models for determing (i) the noise resulting from sources such as traffic (e.g. JURUE 1975), and (ii) its propagation (e.g. DELANEY 1972). Various ecological factors are mapped, including a particular study of landscape quality. The remaining attributes are discussed through qualitative and tabularinformation derived from standard District Authority surveys and secondary data from the North-West Regional Water Authority.

In relation to the criteria stated at the beginning of this section, the following conclusions may be made.

(a) Each study is conducted in explicit connection with the demands of a policy context, although in the studies by Wood et al and Karpe and Scholz the context is hypothetical. Study areas are delimited by the juridictional boundaries pertaining to the policy contexts, and the scales are those of conurbations or sub regions.

(b) A wide range of environmental attributes is examined, covering those aspects of the environment over which the policy contexts may have some control. In this sense the studies may all be termed 'environmentally comprehensive'.

(c) Most of the data are obtained from secondary sources, and so the studies have little independent choice over the indicators used. Indeed, although in some cases fieldwork is undertaken to obtain data specifically for the studies, the task of available spatial data for some attributes (noise, for example) frequently limits the range of attributes which may be described spatially.

(d) Wherever possible, attributes are mapped for the whole study area; in this sense the studies may be termed 'spatially comprehensive'. Use is made of both isolining and choropleth mapping techniques.

(e) Predictive techniques are seldom used, and detailed theoretical and analytical approaches are comparatively rare.

From these conclusions it is evident that the research described in this thesis has much in common with the general context of this kind of study, particularly in respect of the close and explicit attention to the demands of a policy context, and the spatially and environmentally comprehensive approach.

In analytical terms however the research makes a more rigorous approach than the contexts of the general studies have commonly allowed, and in this respect the research is linked more closely to the 'individual attribute' type of study, as the following section shows.

1.3.2 <u>Analytical Studies of Individual Attributes</u>

The studies described above rely heavily upon secondary source information because of the impracticably large resource commitment necessary for surveys designed to achieve spatially comprehensive measure-ment data describing several attributes over an area the size of a conur-bation or sub region. Where only a single attribute is treated the pros-pect becomes more feasible, especially if smaller study areas are chosen, and the specialist studies usually involve primary data collected specifically for the study itself. Such studies have tended to incorporate a deeper theoretical and analytical approach, and to have more seriously considered the issue of prediction, since they are normally set up with these substantive issues in mind, rather than simply as means of obtaining information to aid the wider planning context. The theoretical and methodological problems of spatial representation therefore have the uppermost importance, and much of the work described in this thesis, which is primarily concerned with the development of mapping methodology, is derived from these kinds of study. Consequently the technical substance of the issues encountered in these studies is discussed in due course, as part of the relevant chapters (5, 6, 7 and 8) where the technical aspects of the research are developed, and at this stage it is only necessary to make a summary.

Despite the fact that primary measurements are usually made and only individual attributes are treated, it is still commonly infeasible to obtain by measurement alone sufficient data to describe fully the conditions over areas the size of a conurbation or sub region (i.e. some 600-1500 sq.Km). With ambient noise for example, the studies by SENKO and KIRSHNAN (1971), SAFEER (1973), PRICE (1972) and TOKYO METROPOLITAN GOVERNMENT (1976) have shown the extensive sampling exercise that is necessary if the spatial variations of the ambient noise pattern are to be fully represented in the data.[1] Long-term air pollution conditions exhibit lower spatial variability and therefore require a lower sampling density, but on the other hand the temporal variability is high and unpredictable, and requires a monitoring rather than short-term sampling approach; studies of Reading (MARSH and FOSTER 1967) and Sheffield (GARNETT 1967) show that an extensive monitoring programme at some fifty sites is necessary to allow a purely empirical

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1. For example, 20 sampling sites per square mile are recommended (i.e. approximately 9 per sq. km.).

depiction of the spatial pattern of sulphur dioxide to be made over even these moderately sized cities.

As a means of overcoming the problem of obtaining a spatially comprehensive representation of conditions, most specialist studies have attempted to develop methods for predicting conditions at a point or over an area on the basis of other readily available or measurable parameters, usually associated with the source or cause of the attribute. Predictive relationships which examine conditions due to a single given individual source are not particularly useful in spatial studies of the ambient environment since a characteristic of urban ambient environments is that they are associated with a multiplicity of sources and types of source, a comprehensive knowledge of which is impracticable over an urban area. Consequently spatial studies tend to treat sources in the aggregate, using area-based parameters to act as the predictor variables in a spatial model. This notion of the 'area-based spatial prediction model' is adopted quite explicitly in urban air pollution modelling (e.g. GIFFORD and HANNA 1973, SHARMA 1975, BENARIE 1976) and lies behind the classification of noise conditions by area type as performed by BRITISH STANDARDS INSTITUTION (1967, 1975), PRICE (1972) and TOKYO METROPOLITAN GOVERNMENT (1976). A similar theory underlies the procedures for classifying residential area environments (BUCHANAN 1971) and landscape attractiveness (SOUTH YORKSHIRE COUNTY COUNCIL 1978b), as will be seen in later chapters.[1] In essence this approach is the same as that expressed in Wood's 'subregional wastes-pollution spatial model' but with a less explicit description of the pollution process.

In relation to the criteria given earlier, the following points are

1. In the latter two cases the attributes are of course area-based rather than point-receptor measures - this distinction is amplified in Chapter 3.1.

evident.

(a) Specialist studies are usually designed to respond to analytical objectives rather than policy contexts

(b) A single environmental attribute is chosen for study

(c) Indicators can be designed to suit the study purpose since primary data are often collected as part of the study. Theoretical issues such as the sampling density necessary to achieve a given accuracy or representativeness are frequently considered

(d) Isolines or choropleth techniques may be used, and the sampling and analysis process may be modified to accommodate the needs of the spatial representation technique

(e) Prediction is often introduced as a substitute for collecting spatially comprehensive measurements, so reducing the fieldwork to a calibration exercise.

As already stated, it is in the analytical depth of these studies that the strongest links with this research are found.

This section has provided a brief description of the various types of study which have investigated the spatial pattern of urban environmental conditions. The context of the research is clearly identified with the 'comprehensive' category of studies, but the most attentive treatment of the methodological issues such as prediction has been made in the 'specialist' studies. To an extent the research is intended to synthesise the two approaches, through the development of a comprehensive mapping methodology using the concept of the 'area-based spatial prediction model'.

1.4 THE KEY ISSUES IN URBAN SCALE ENVIRONMENTAL MAPPING, AND THE AIMS AND OBJECTIVES OF THE RESEARCH

The purpose of this section is to summarise the key issues in urban-scale environmental mapping with reference to the foregoing reviews, and to outline the proposed aims and objectives through which the research responded to these in the development of the TAE mapping methodology.

1.4.1 The Key Issues

Table 1.2 presents a summary of the most critical issues which need to be approached in the development of a mapping methodology within this research context.

Broadly Theoretical Issues	Broadly Operational Issues
1. Spatial respresentativeness of observations and criteria of representativeness 2. Cartographic representation method and its interpretation, e.g. through zoning, isolines etc. 3. Predictive relationships between an attribute and parameters relating to its source or cause 4. Spatial covariance of environmental attributes leading to 'key indicators'. 5. Aggregation of attributes to achieve an overall representation of environmental conditions.	1. Achievement of a comprehensive spatial coverage of a diverse range of indicators representative of general environmental conditions, within budgetary constraints. 2. Design of indicators and measurement, method to take account of temporal variance and policy context. 3. Design of a sampling method which is responsive to spatial variation through sampling density and location of observations. 4. Representation of pattern through maps appropriate to the environmentally comprehensive context, i.e. patterns may be compared, and applied to policy context.

Table 1.2 Key issues in the spatial analysis of ambient environmental conditions

The issues have been divided into those which concern the relationship between the methodology and a theoretical knowledge of the nature of spatial environmental pattern (the 'theoretical' category), and those which are concerned with the operation of the methodology itself and its response to operational factors (the 'operational' category). It is clear however that the issues themselves are interrelated in a complex way, and so this classification can give no more than a very general structure for the issues.

Considering those issues classified under the 'theoretical' heading, the first two are centrally concerned with the problem of spatial representation, the critical questions concerning which are: over what area and for what period of time is any given observation representative? What criteria should be used to decide when the limits of representativeness have been reached? To what extent may the true and varied nature of environmental conditions within a zone be represented by data? If isolines are used, how is interpolation to be achieved? If the choropleth technique is used, what is the optimal size of zone, and how should the zones be designated? A critical examination of these issues is limited in the literature to a few studies of urban noise and air pollution (e.g. SAFEER 1973, BENARIE 1976), and to the study by WOOD et al (1974), where the issues of zoning, and the spatial variation of conditions within and between zones, are treated. At the more theoretical and abstract level there are further considerations (e.g. MASSER and BROWN 1978, DICKINSON 1973), and in Chapter 3 the thesis develops these issues in greater depth since they lie at the core of the research theory. A further key theoretical element is the spatial relationship between environmental conditions and parameters with which the conditions are causally related. The use of such relationships to predict conditions where measurement is infeasible has already been referenced in relation to the individual attribute studies, while the 'subregional wastes-pollution spatial model' proposed by WOOD et al (1974) extends a more explicitly dynamic approach to predictive mapping. In this context and in consideration of the potential uses of 'key indicators' (where a given indicator measure reflects a range of concerns), a knowledge of the spatial covariance of environmental conditions is of direct interest. Moreover, in the study of the 'aggregate environmental indicator' problem in Chapter 8, the existence of spatial covariance is seen to be of considerable advantage in the development of an aggregate spatial model. Both the studies by WOOD et al (1974) and KARPE and SCHOLZ (1976), as well as an extensive contemporary study by the EEC (AMMER 1976) and the SOUTH YORKSHIRE COUNTY COUNCIL (1978b), have shown the value of aggregate mapping exercises in spatial environmental policy contexts.

As regards the actual performance of a mapping methodology and its relationship to the operational context, a crucial issue common to both general and specific attribute studies was shown to be the achieving of sufficient spatial data to allow an area the size of a conurbation or County for example, to be mapped within a tight budgetary constraint. Associated with this to some extent is the issue of the appropriate sampling density of observations, and the design of a sampling technique which will allow representative, 'ambient' conditions to be measured through an indicator which also reflects the interests of the policy context. Since most general studies rely on secondary sources of data, the experience is that they have little influence over these issues and consequently little choice about the methods of spatial representation - for example in Wood's study it was necessary to represent the data in terms of Local Authority zones despite the obvious demand for a less arbitrary and more spatially regular and precise representation (WOOD et al 1974).

The above gives a basic summary of the issues which surround the research problem. In response a set of aims and objectives for the research was laid out through which most, although for reasons of practicability not all, of these issues were examined and investigated in the development of a mapping methodology. These aims and objectives are discussed below.

1.4.2 Aims and Objectives of the Research

The aims and objectives of the research are summarised in the 'framework matrix' shown in Table 1.3. It is seen that the research is classified through two independent dichotomies, one relating to the research function, and the other describing the research method through which the issue is examined. The functional dichotomy distinguishes those aims and objectives which relate essentially to the methodological development of a mapping technique, from those whose function is to develop and extent substantive knowledge about the nature of the urban environment and the application of

Table 1.3 Framework for Classifying the Aims and Objectives of the Research

Dichotomy by Function / Dichotomy By Method	Methodological Aims/Objectives (Concerned only with the development of a method for environmental mapping)	Substantive Aims/Objectives (Establishing theoretical knowledge and causal factors relating to environmental conditions, and the broader significance for environmental policy)
Broad Aims (Qualitative, discursive method involving theoretical analysis and review)	(a) Develop a conceptual framework for environmental measurement and prediction. (b) Investigate theory of spatial representation with respect to operational and theoretical issues (c) Extend current mapping methodologies through the area-based spatial prediction model.	(a) Review the application of environmental mapping to operational policy contexts. (b) Establish urban fabric parameters as the key determinants of spatial environmental pattern
Specific Objectives (Qualitative empirical investigation of specific hypotheses through case study data)	(a) Test methods for classifying areas using urban fabric types, expressing the results in prediction models to be used for mapping (b) Address the problem of defining and measuring environmental indicators for use in mapping (c) Address the problem of optimal zone size for the area-based model	(a) Test the hypothesised relationships between urban fabric categories and ambient noise, sulphur dioxide air pollution, and area appearance (b) Test the spatial covariance of ambient noise, sulphur dioxide, and area appearance (c) Address the problem of achieving an indicator of aggregate environmental conditions.

the mapping methodology to substantive policy issues. The dichotomy of research methods shows that some issues are treated at the broad, qualitative level through discussion, theoretical analysis and review, while other specific objectives are identified in which quantitative, testable proposals are made and specific hypotheses are examined at the empirical level over a case study area.

The contents of Table 1.3 summarise the aims and objectives of the research under the general title of the research problem, the development of an environmental mapping methodology appropriate to the local government context. There is not a direct, systematic response to the issues listed in Table 1.2 since these issues are, as stated, interlinked and the pursuit of a given objective encounters a number of the itemised issues. A further point should be noted concerning the role of the 'framework matrix' in Table 1.3. As with all methods of classifying topics which possess strong interlinkages within a general problem area, the explicit itemising and delineation of categories is an artificial exercise which belies a complex interrelationship between the objectives, and as such these individual topics are seen to be properly consistent only when considered as a whole. Nevertheless the framework matrix does attempt to reflect a genuine distinction between the roles and methods of study characterising the various aims and objectives of the research.

1.5 CONCLUSIONS, AND SYNOPSIS OF THE THESIS

1.5.1 General Conclusions

This chapter has set out a general context to and summary of the research problem. In brief the following conclusions concerning the key issues and context for the research may be made:

(i) Spatial environmental data (in the form of maps) are of considerable importance in policy contexts where issues with significant environmental content are encountered. A list of examples of these policy contexts is given in section 1.1.2, and local authority planning at the strategic, urban scale is seen to provide the most prominent generalised context.

(ii) The mapping methodology that is adopted to suit these applications must be spatially and environmentally comprehensive; however this objective encounters considerable methodological difficulties.

(iii) The demand is for a simple, cheap, versatile, readily applied methodology using easily obtained data.

(iv) Technical aspects of the methodology, such as the choice of indicators, sampling density and method, representational (cartographic) technique, aggregation method, and overall accuracy, must respond to the operational needs and constraints of the policy context as well as the strictly theoretical issues surrounding measurement and prediction. A tabulation of these issues is given in Table 1.2, section 1.4, and they are examined more deeply in the following Chapter 2.

(v) The research has linkages with both the general environmental studies in contemporary research (through its context and the explicit recognition of the demands of general policy issues) and the specific studies of individual attributes (through the detailed attention to theoretical and analytical matters).

The aims and objectives of the research are designed to meet the key issues outlined above. The following chapter examines the extent to which these aims and objectives provide a properly comprehensive coverage of the issues.

1.5.2 A Synopsis of the Thesis

Having now established a general review of the research problem, the following chapter 2 completes the introduction to the research by discussing a conceptual framework through which the linkages between the research and its operational and theoretical contexts are made more explicit. Chapters 3 and 4 expand and the theoretical and conceptual basis of the mapping method developed in the research; Chapter 3 discusses spatial representation and the adoption of the TAE concept as the basis of the spatial prediction modelling approach, while Chapter 4 establishes the research hypotheses and the experimental design through which they were tested and the mapping models developed and applied. The subsequent four chapters present the bulk of the technical findings of the research in relation to the four case studies, covering ambient noise, sulphur dioxide air pollution, area appearance and aggregate environmental conditions respectively. In each of these chapters the key empirical problems are examined, the empirical methods for validating the hypotheses, calibrating the TAE prediction models and applying them as mapping methods are described, and the performance and characteristics of the TAE methodology are compared with the methods of other equivalent studies. The thesis concludes with an assessment in Chapter 9 of the performance of the research in relation both to its aims and objectives and to other equivalent studies; suggestions for further research are also made.

CHAPTER 2

A CONCEPTUAL FRAMEWORK APPROACH TO THE RESEARCH PROBLEM

2.0 SUMMARY

A recurrent theme throughout the first chapter of this thesis was the interrelationship between issues of policy and theory. The role of this Chapter is to make this relationship more explicit, developing in conceptual terms a framework through which the various contexts, demands and constraints that bear upon the research may be structured. The development of a conceptual framework in this manner serves three main purposes:

(i) the complexity of contexts and linkages may be elaborated, thus increasing an understanding of the research problem;

(ii) a properly comprehensive range of key issues may be developed, from which it may be seen that the research (through the aims and objectives already identified) makes a substantial response to some of the issues raised, whilst covering others in rather less detail;

(iii) the conceptual framework may be used subsequently in the research as the basis upon which to analyse and compare the performances of the research and other equivalent studies with respect to the complementary requirements of policy and theory.

In section 2.1 the theoretical context is outlined, enlarging upon the issues of definition, measurement, modelling and causality, and errors, that have been touched upon already in Chapter 1. The operational context, discussed in section 2.2, summarises the roles of local government also mentioned in Chapter 1, the systems approach to planning, and the operational content of planning policies and actions. From these perspectives the conceptual framework is laid out in the form of two diagrams in section 2.3, which also identifies the set of theoretical and operational demands and constraints influencing the research problem, and discusses the extent to which these are given attention in the research. This then completes the description of the general research context with which the first two chapters of the thesis are concerned. The subsequent chapters describe the research itself, commencing with the analysis and development of the research theory which led to the concept of the TAE and the 'spatial prediction model' mapping methodology.

2.1 THE THEORETICAL CONTEXT

As discussed in section 1.2 and to a limited extent in section 1.3, the main theoretical issues which which the research is concerned are those associated with the measurement and prediction of ambient environmental conditions. These issues are encountered empirically in the need to derive and use empirical data as a basis for the validation, calibration and application of the proposed TAE mapping methodology. In brief, the issues comprise definition, measurement, indicators, causality, models, hypothesis testing and errors.

2.1.1 Definition

Pure science has traditionally relied upon 'conceptual' definitions, in which the concept to be defined is related to other concepts whose meaning is assumed to be understood. This paradigm rests on the essentially platonic view that all concepts exist of themselves in a formal relationship which it is science's purpose to uncover. With the development this century of the so-called 'soft'[1] sciences, the alternative,

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1. The distinction between 'hard' (or 'pure') science and 'soft' science, so far as definition is concerned, is that the former category professes an established tradition of ideas, theories, procedures, concepts and relationships ('Laws') that are unambiguously and universally tested and acknowledged. These may therefore form the basis of universal concepts which may be used in definition. In the latter category such aspects of the science are not well established due to factors such as the infancy of the field of study and the lack of an obviously testable basis for its propositions.

'operational' approach has been promoted through the understanding that "in general, we mean by any concept nothing more than a set of operations; the concept is synonymous with the corresponding set of observations" (BRIDGMAN 1927); the process of definition thus consists of "referring any concept for its definition to the concrete operations by which knowledge of the thing in question is had" (STEVENS 1935). This operational approach was arrived at from the understanding that science is distinguished as a human activity by the fact that its theories and statements are testable (ACKOFF 1962), and the particular objective of the operational method in respect of the 'soft' sciences, is to allow science to bridge the gap between theories, which are formulated at a conceptual level, and operational research, whose object is to test the hypotheses developed.

With regard to this research, the earlier discussion in 1.2.1 has highlighted the difficulties encountered in environmental definition, and the infancy of this applied science and the consequent comparative lack of established definitional practice. It may be concluded therefore that an operational approach to definition is required in the research case studies. The content of all such definitions is expressed in terms of objects, events and their properties. The properties are the central components and may be divided into <u>structural</u> properties (relating to the physical content or form of the object or event) and <u>functional</u> properties (describing what it does, how it came to exist, i.e. what produced it or what it itself produces).

The operational definitions of the case study attributes are given in the respective case study chapters. It should be noted that although there are evidently many possible operational definitions of each attribute the 'meaning' of the attribute is in each case taken to be limited to the particular operational definition selected.

2.1.2 Measurement and Indicators

The operational approach to definition is clearly linked to the issue of measurement, since the definition is established upon the way in which observations are made. Measurement aims to "establish metrical order among different manifestations of particular properties, ... so making scientific events amenable to mathematical description" (COWS 1959). Thus the prime aim of measurement is to represent the content of observations by symbols (usually but not necessarily numbers) "which are related to each other in the same way that the observed objects, events or properties are" (ACKOFF 1962). Note that the properties of these symbols (known as scale properties) do not describe the formal properties of that which is being measured, but the properties of the observations which can be performed on that which is being measured. Four types of scale property are found; nominal (or classificatory), ordinal (ranking), interval, and ratio (both termed cardinal). The importance of the scale properties of measurements lies in the valid mathematical manipulation which may be performed upon the data of that particular kind; in the environmental field these limitations are particularly critical in the addition, multiplication, weighting and aggregation of environmental measures. The chapters in this thesis which describe the empirical case studies make frequent reference to the constraints imposed by the scale properties of the data.

In some contexts it is more convenient or expedient to make measurement indirectly. This becomes possible in cases where a correlation is observed, or proposed intuitively, between the results of the operationally defined measurements themselves and a further set of operations; this further set of operations may then be said to define an 'indicant' of the concept of interest (STEVENS 1951). A common example in the environmental policy context is to be found in the use of indicators, as seen shortly. Through a simple and readily operated set of observations an indicator is defined which is taken to represent the condition of a complex environmental condition or set of conditions. Such indicators are particularly appropriate in policy-related measurement contexts where it is necessary to isolate relevant information and present it in a condensed form. In this type of context the value of indicators is that a small number may provide a highly meaningful picture of what is going on, their effectiveness relying on the information being sharply focussed, stimulating, readily comprehensible and related to policy performance or critical policy-related target areas (PERCOFF 1972, OECD 1976). Through aggregation, 'primary indicators' may be derived which represent the combined conditions of several attributes; alternatively a 'key indicator' (e.g. sulphur dioxide concentrations in the case of air pollution) may be selected to represent the combined effects of several attributes (a detailed study of aggregation issues is made in Chapter 8).

In the discussion on public policy and the environment in Chapter 1.1 it was observed that environmental conditions constitute a policy issue because they may affect people's physical or social well-being. In more general terms it may be stated that environmental conditions pose a stimulus which elicits a response in respect of man's[1] health or welfare. Clearly, in the final analysis it is the response with which public policy is concerned, and therefore which measurement is ultimately required to reflect. In other words, environmental measurement should either measure response directly, or should measure environmental conditions (the stimulus) in such a way that the measurements correlate with the response. The latter approach uses the idea of 'indicancy' examined by STEVENS (1951), and in addition to being simpler than measuring the responses of a large population, it explores causal factors (see the following section 2.1.3) and is therefore more useful.

1. In broader ecological perspectives, the responses of animals and plants are also considered, and the argument may even be extended to include the 'response' of inanimate matter, as in the study of the effects of air pollution on corrosive building fabrics.

However, there are considerable methodological problems in devising a measurement tool that is a reliable indicator of response. In the cases where health effects are of interest, the physiological differences between individuals (resulting for instance in the fact that children are more sensitive to a given concentration of pollution than are adults) mean that environmental measurements cannot reflect the responses of all individuals equally, and thus particular measurements are commonly interpreted in terms of the likelihood that they will be accompanied by a given response in a given proportion of the population. Welfare effects are even more problematical since response is also determined by the subjective, sociological, perceptual and psychological characteristics of individuals. Thus it is evident that the development of measurements of the environmental stimulus that mirror man's response is a highly complex research area in itself, and no attempt to investigate this area was made in this research. Instead, the case studies were based on simple operational methods for measuring the physical environmental stimulus, and the evidence for an association between the resulting measures and human response was asserted where applicable purely on the grounds of other research.[1]

2.1.3 Causality and Association, Theory and Models

The analysis and prediction of environmental conditions, and particularly the development of a dynamic mapping methodology, is dependent upon the establishment of a valid body of theory on the causes of variation in environmental conditions, and it is also necessary that these relationships be modelled in a simple yet useful and valid way. Modelling, particularly when the objective is to achieve predictions, simulation and forecasts, seeks "stable relationships" (LOWRY 1965) as a reliable and valid foundation; HARRIS (1967) supplements the point by holding that a model is "an

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1. The whole question of environmental stimulus and human response, and the role of measurement, is discussed in greater detail in the case study of area appearance, Chapter 7.1.

experimental design based on theory", a view which underlines the importance of the linkage between modelling and theory.

A theoretical understanding of relationships is rooted in the analysis of causality and association. ACKOFF (1962) has identified three classes of association between variables;

(a) cause-effect, where x is necessary and sufficient for y (deterministic causality);

(b) producer-product, where x is necessary but not sufficient for y (probabilistic causality);

(c) correlation, where x is not known to be either necessary or sufficient for y, but both tend to be observed present or absent together (causality may not be involved at all).

An observed association may only be classified according to the above on the basis of empirical research; for example, it is only on the grounds of repeated observation that it is possible to say that "x has never been observed with y absent, and has always been observed with y present" and to conclude that "x is necessary and sufficient for y". The assumption must be made that all influences upon y have been identified and included in the set x, but the only grounds for this assumption ever to be established are empirical. Causality in the final analysis has to be inferred not deduced; it is not a deduction but a metaphysical assumption that allows a transition to be made from "x is always followed by y" to "x causes y".

Causal inference on empirical grounds is confronted with a number of problems;

(i) spurious relationships, where x and y are associated, but through the effect of an intermediate variable;

(ii) correlated 'independent' variables, where variables correlated with a dependent variable may be correlated amongst themeselves and act as a single 'syndrome';

(iii) measurement errors, which act as additional unknowns;

(iv) interaction effects, where the strength or nature of a relationship is dependent on the state of the variables;

(v) reciprocal causation, when x affects y and y affects x.

(BLALOCK 1973)

Again it is only empirical evidence that may allow the researcher to disentangle the relationships, and so it is evident that the establishment of causality is frequently a complex analytical problem requiring extensive data and controlled experimentation. The limitations that causality issues impose on the hypothesised basis of the TAE methodology are discussed in Chapter 4.2 and in the chapters describing the case studies.

Returning to the issue of modelling and the linkage with theory, it is notably paradoxical that although a model, as a simplification of the real-world, relies on a theoretical view of the real-world form and dynamic, it is difficult for theory itself to become established (especially in new applied science) unless models are actually used and developed, particularly in the context which they intend to represent. Modelling may therefore be seen as a learning method. Six key issues surround the development of models:

(i) selection of appropriate variables and indicators;

(ii) the level of aggregation;

(iii) the treatment of time;

(iv) specification of relationships, preferably through mathematical foundation;

(v) calibration of parameters, coefficients and constants;

(vi) validation, based on an evaluation of the results "in terms of the extent to which the theories represented by the models can be shown to represent real situations" (MASSER 1972) - a process, like causal inference, relying upon empirical evidence and intuitive judgement.

It will be seen in the Chapters describing the case studies that the TAE prediction models, upon which the mapping method is based, result from an analytical procedure in which each of these issues has to be treated.

2.1.4 Errors

The greater the degree of complexity and aggregation in a model, the greater is its susceptibility to the compounding of errors (ALONSO 1968). This fact leads to the need for an optimal complexity in models which will depend on the intrinsic errors in the model and the relative importance of accuracy in the model's application and context. Errors do of course occur at all stages in systematic scientific analysis, as depicted in Fig. 2.1 and described below.

(i) Indicancy error occurs whenever a specific operational definition and measurement is used as a surrogate or indicator for the properties which are of true interest, and the relationship is probabilistic.

(ii) Sampling errors occur when the phenomena under observation exhibit either probabilistic properties, or spatial or temporal variance in circumstances where only a sample period or location may be observed.

(iii) Measurement errors may be due to, (a) the observer (random or bias errors), (b) the instruments (also random or biased), (c) variation in the 'standard' conditions under which observations should be made, and (d) active or passive anomalies in the response of the observed properties, resulting from either peturbation by the actual act of being observed, or untypical response.

(iv) Prediction and forecast errors are associated with the modelling process, especially in the stages of calibration (leading to bias), specification (bias and random error) and validity (indicancy and spurious association); in addition, risk and uncertainty beset the forecasting of future conditions.

(v) Hypothesis testing errors are associated with the basic procedure of attempting on the evidence of empirical data to disprove a null hypothesis; Type I errors involve the rejection of the null hypothesis

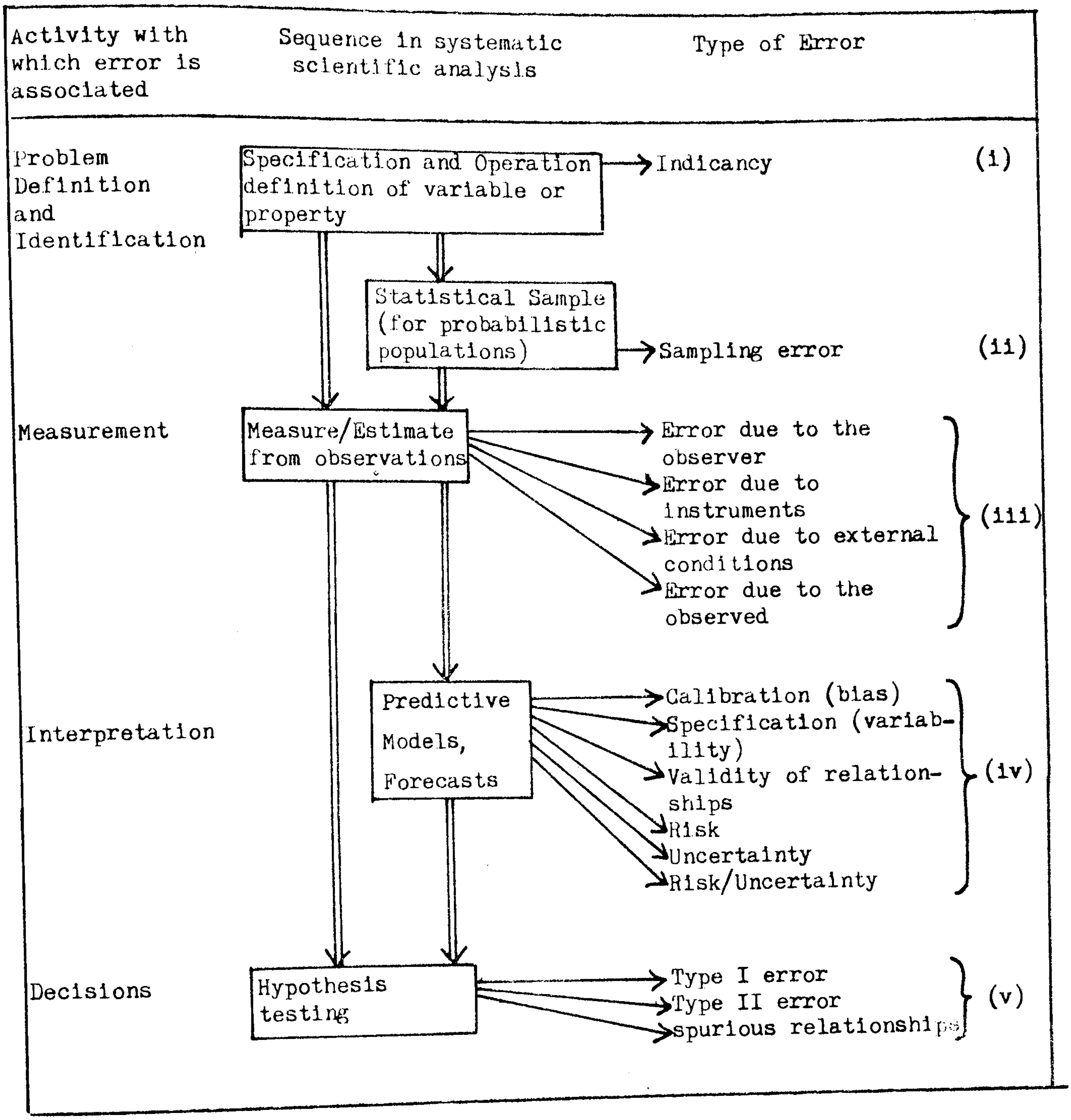

Fig. 2.1 Errors in systematic scientific analysis

when it is in fact true - the chance of this may be set by the researcher - and Type II errors involve accepting the null hypothesis when it is false. In addition there are instances where empirical data will support a relationship which is spurious.

Fig. 2.1 proposes a comprehensive taxonomy of the errors encountered in systematic scientific research. Seldom however does sufficient data exist (and indeed seldom is scientific research so thoroughly systematic) to allow all types of error to be identified and quantified. The research case studies are no exception to this, but errors are identified and quantified wherever the data and the research make this possible.

This summary of theoretical issues has attempted to touch upon the broad range of topics which affect the technical aspects of the research. The importance and particular effect of these issues in the research have been outlined here and in Chapter 1, and a deeper analysis of the key area of spatial theory is made in the following Chapter 3. At this stage the role of the section has been to substantiate the theoretical element in the conceptual framework for the research which is presented in section 2.3.

2.2 THE OPERATIONAL CONTEXT

The purpose of this section is to outline the nature of the operational context in which it is suggested the mapping methodology is most applicable. The discussion in Chapter 1 on environmental policy showed local government planning to be potentially the most fruitful area, and consequently this section sets out to describe the local government context and the role of planning, and to analyse the systematic nature of planning and policy analysis; it will thus be made more clear (in both this and the following sections) how the research is related to the system of public planning.

2.2.1 Planning and the Role of Local Government

The role and actions of local government may be elucidated through reference to the simplified conceptual diagram in Fig. 2.2. This indicates the systemic relationship existing between five categories of agent (one of which is local government) that together are seen as constituting the participants in a 'government - community' dialogue. The policies of local government are therefore understood to be determined by pressure from both central government and the community, as well as the local government institution itself.

Aston University

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Fig. 2.2. The major forces acting between the five classes of agent (Source: SOLESBURY 1974).

In this simplified structure, the community system involves (a) operators, consisting of retailers, manufacturers, providers of goods and services in the widest sense; (b) developers, who provide the fixed building stock, plant, vehicles and roads through which goods and services are provided, and (c) consumers, constituting the public at large who take the products of the operators and developers. The government system divides into (d) local government, acting to promote (via public operations and developments) or regulate (via responsive control of private operations and developments) the local activities, and (e) central government, which possesses more diverse controls, some directly or indirectly over (a), (b), (c) and (d).[1] The pressure which moulds the role and actions of the local

1. There are obviously other institutions of community and government; Chapter 1 has mentioned some in the environmental field (e.g. Alkali Inspectorate etc.).

authority thus arises from three sources;

(i) the community system, via formal application for grants, rebates, aids, permission, etc; and informal pressures through trades councils, chambers of commerce, residents' associations, community action groups, etc;

(ii) the central government via statutory obligations (e.g. Town and Country Planning Acts), or advice and exhortation backed by inducements of finance;

(iii) the local authority, via the political/social ideology of the elected members, and the professional ideology, expertise and knowledge of the practitioners.

(This conceptual structure is due to SOLESBURY 1974).

Because many pressures and local authority actions are potentially interactive and marginal, and because of overall response constraints, and statutory and institutional limitations to action, the local authority is faced with an 'economising' management problem, trading off policies and actions in order to meet the optimal satisfaction of the pressures and demands. This may be achieved through the two broad categories of <u>responsive</u> and <u>promotional</u> action. Responsive action is highly diverse and relates to those kinds of action in the community system which have been made subject to local authority approval, either prior to their taking place (as in development control) or while or after they have happened (as in the law relating to nuisance). Promotional action may involve influence or inducement of the actions of operator and developer through the provision of information, grants, loans, favourable lease terms, etc., or promotion through the local authority's own planning policies as expressed in development plans. Development planning is currently divided between the two tiers of local government as shown in Fig. 2.3 with the County Structure Plan providing a framework of strategic policy from which the District-level plans and programmes take their initiative.

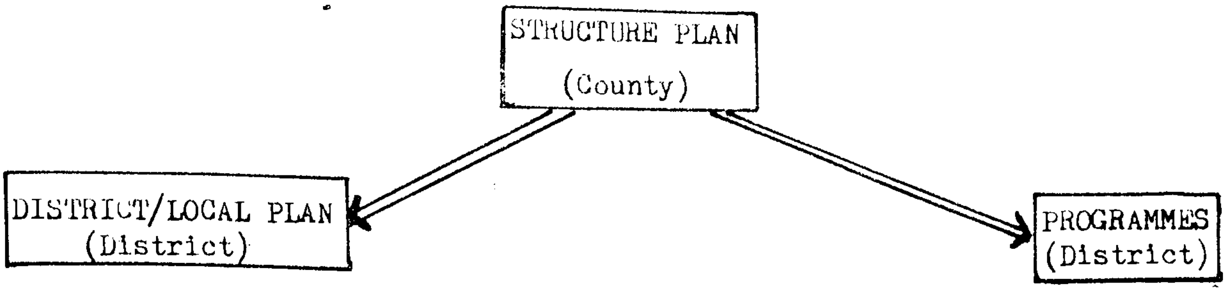

Fig. 2.3 Framework of Development Planning in the UK

Environmental issues in the local authority context have been outlined in Chapter 1, and this section allows them to be seen in the wider perspective of local government activity. The general statutory division of environmental responsibilities is listed in Table 2.1

Districts	Counties
Land use and development	Land use and development
	Highways
Public transport	Public transport
Parking	Parking
Building standards	
	Waste disposal
Air pollution	
Derelict land	Derelict land
Coast protection	
Building preservation	Building preservation
Tree preservation	Tree preservation
Housing	Housing
Land acquisition	Land acquisition
Parks and open space	Parks and open space
Advertisements	
	National parks
Country Parks	Country parks
Town development	Town development
Footpaths	Footpaths

Table 2.1 Allocation of environmental executive responsibilities in the UK

(Source: SOLESBURY 1974)

In the responsive approach to environmental issues, local government relies heavily upon the statue and common law, through which it pursues its responsibilities under the pressures from the 'five agents' system. In contrast the promotional activity gives more initiative to the planning authority. For example the general aim of development plans should be "to satisfy the social and economic aspirations of the community as far as possible, through the creation of an efficient physical structure, with a good environment" (MHLG, 1970). While the focus of development planning is in general on physical development, land use planning is intended to be integrated with transport planning and other factors, for example the physical environment, regional planning, and social policy. Thus there is in this at least a basic framework for a comprehensive planning approach, such as was seen in Chapter 1.1 to be necessary in order to permit a properly integrated and rational environment policy.

2.2.2 Systems Planning and Policy Analysis

Having outlined the general context of the roles and actions of local government, it is appropriate now to analyse the systematic nature of planning and policy analysis, in order that the relationship between the type information resulting from this research and the general nature of the planning process may be understood.

"Planning is a process of preparing a set of decisions for action in the future, directed at achieving goals by preferable means" (DROR 1968). This statement summarises the rational, purposive paradigm of planning, developed as a means of overcoming the problems that were encountered in the 1950's and 1960's resulting from excessively normative, subjective, intuitive decision making. Rationality and purposiveness in decision making, now conventional characteristics of current planning method, require a systematic procedure for the analysis of policy. This may be achieved through pursuing an approach based on a conceptualised structure of the function and operation of planning activities. The functional hierarchy of activities passes from analysis, through design, to policy (WILSON 1970) as seen in the conceptual diagrams described shortly. The operational sequence in the actual conduct of policy analysis is seen in a set of stages, for example:

(i) objective formulation and problem identification;

(ii) generation of plan or policy alternatives;

(iii) evaluation of alternative proposals;

(iv) implementation;

(v) monitoring

(JURUE 1976)

The systems approach to planning has led to the development of a range of planning techniques which respond to and serve the various functional and operational components in policy analysis; these may be classified into analytical, procedural and political techniques. In the context of this research the analytical and procedural techniques are significant (and are described below), while the political techniques are only relevant in respect of the presentation of environmental information in a form which may be readily understood by politicians and the public in general.

(i) Analytical techniques centre on the use of base data, predictive and forecast modelling, simulation, urban theory and other information in order to enhance technical knowledge of the issues relevant to the planning context. The research described in this thesis was concerned primarily with this type of planning technique.

(ii) Procedural techniques revolve around the central themes of evaluation, but include decision analysis and sensitivity analysis as associated techniques. Their main purpose is to facilitate the technical procedures through which the administrative agency makes decisions (ALDEN and MORGAN 1974). It is important to note that their operation is crucially dependent upon the data base provided by the analytical techniques.

Evidently the procedural techniques are specifically designed to aid the topmost, 'policy making' level in the Wilson hierarchy, although sensitivity analysis and evaluation are also applicable at the 'design' level, and even to a limited extent at the 'analysis' level. The analytical techniques are by the same token rooted in the 'analysis' level, but also feed indirectly to the others: (a) the 'design' level is facilitated through theory building; this is an essential component of both modelling and hypothesis testing, which are crucial analytical techniques; (b) the '<u>policy making</u>' level is aided by the flow of analytical information into the procedural techniques of evaluation and decision analysis, and also through the input of plan designs based on theories and models established at the analytical level. The structure of this conceptual system is illustrated in Fig. 2.4, to be presented and discussed in the following section.

The systems views of planning is characterised by a concern with the wide-ranging, interactive and indirect consequences of planning decisions, and an understanding of the way in which a geographical area and its population functions, develops and responds to the stimulus of planning actions. The value of models is critical, and it should be noted that models may assist the various stages and hierarchies of planning activities in different ways, often taking different forms appropriate to each particular stage or level. However, limitations to the rational paradigm of systems planning are particularly evident in the urban planning context which, more so than the earlier military and industrial applications, is imprecise, qualitiative, value-ridden and subjective, and where relevant data is correspondingly problematical. There appears to be no consensus as to whether the approach can make planning less subjective, and it is also recognised that over-concern with the quantifiable element in planning may cause neglect of the qualitative, intangible factors and the creative task of designing a wide range of alternatives. However despite these misgivings as to the practicality, or even virtue, of objectivity in planning, there is a general agreement that the systems approach enables planning to develop as a 'learning process', and has considerable benefit in making values and choices more explicit, thereby facilitating a more informed debate as the basis for decision making (ALDEN and MORGAN 1974).

2.3 A CONCEPTUAL FRAMEWORK FOR THE RESEARCH

The reasons for setting out a conceptual framework for the research have already been outlined in section 2.0 in terms of the ways in which the understanding, relevance and conduct of the research may be enhanced. The operational and theoretical contexts to the research have been described above, and the relationship of the research to these, together with the resulting demands, constraints and interlinkages, are now made more explicit by expressing than in the form of conceptual diagrams.

2.3.1 The Conceptual Diagrams

Fig. 2.4 Relationship between planning techniques and planning activity (⟵⟶), showing the two principal dimensions of data-need fulfilled by the TAE mapping methodology (⟵⟶).

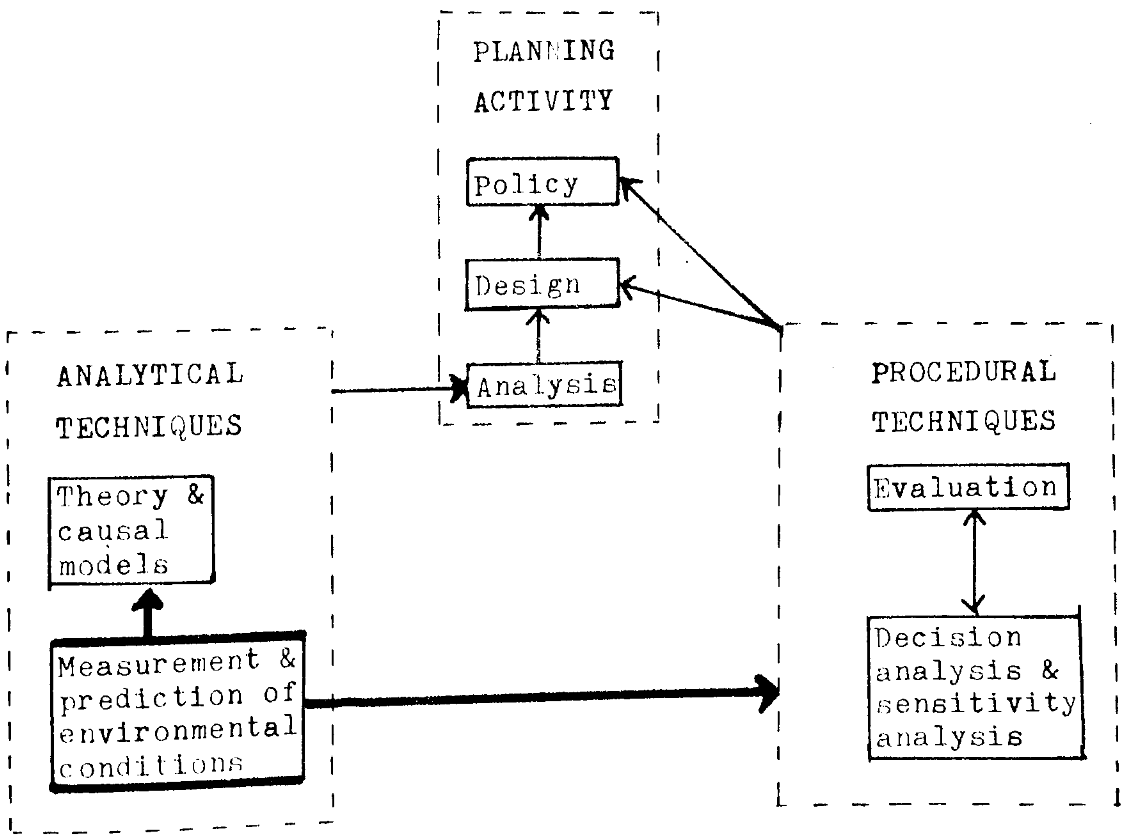

Fig. 2.4 shows the location of the research problem area within the general block of analytical planning techniques. As illustrated, these are linked directly to the analysis level in planning activity, and subsequently therefore to design and policy; the analytical techniques also supply the procedural techniques with information, thus feeding the design and policy levels through a second path. Essentially therefore the research may be seen as fulfilling two dimensions of need, (i) in the development of theory and the construction and testing of causal models - an analytical role; (ii) in the provision of information intended to facilitate design and decision making - a procedural role.

The second conceptual diagram is shown in Fig. 2.5, which gives recognition to the theme underlying much of the foregoing, that both analytical and procedural techniques are subject to the demands and constraints of the optical and operational considerations.

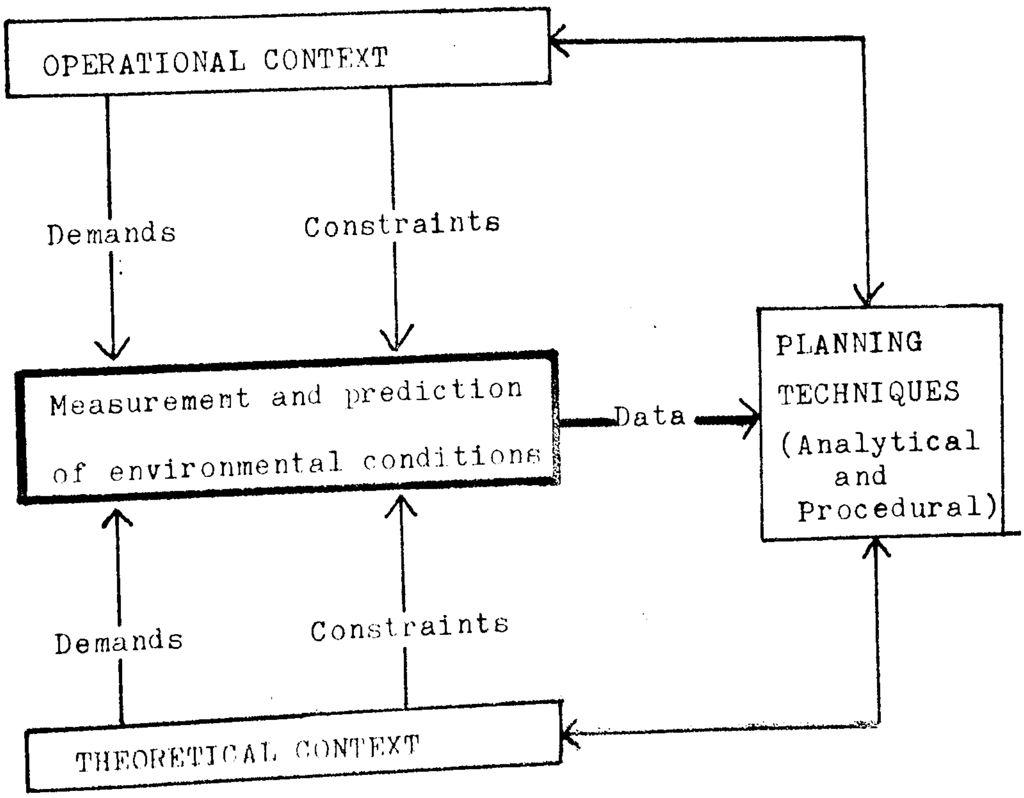

Fig. 2.5. Demands and Constraints, and the provision of Environmental Data within a Framework for the Research

The linkages are seen to be complex and interactive; thus the research, and indeed the planning techniques which are supplemented by it, are seen to be confronted with the distinctly different and frequently conflicting demands and constraints of the operational and theoretical contexts (as described in detail below). Additionally there is a relationship between the classes of technique themselves, for while the availability and formulation of the data constrain the use of procedural techniques, the procedural techniques themselves, once selected, have a reciprocal effect in that they in turn require data to be expressed in particular forms and models. The complexity of the whole system as conceptualised here is due to the dual consideration of policy and theory. A purely academic and theoretical study of environmental mapping would be limited only by theoretical demands and constraints, and the limits of available resources; for this policy-oriented study however the further operational dimension is involved (note that the dichotomy between these two types of study has already been encountered in the review of contemporary research in Chapter 1.3).

2.3.2 Theoretical and Operational Demands and Constraints

The conceptual framework allows the main influences on the research to be classified and structured into operational and theoretical demands and constraints. Colloquially one might say that the research is motivated by demands ("one ought to do this because it is operationally useful or theoretically necessary"), and beset by constraints ("one can't do this because it is operationally infeasible or theoretically unacceptable"). Conceptually the system is equivalent to two optimisation functions with the objectives, (i) to facilitate policy subject to the constraints of theory, (ii) to constrain policy subject to the demands of theory. From a consideration of the contexts as outlined in sections 2.1 and 2.2, the key demands and constraints have been identified and are shown in Table 2.2.

Table 2.2 Theoretical and Operational Demands and Constraints affecting the Research

TYPE OF DEMAND/ CONSTRAINT	DESCRIPTION
Operational demands (demands for relevance and timeliness)	(i) Definition and measurement through indicators appropriate to policy context and reflecting issues of concern. (ii) Data suitable to different stages in the planning process. (iii) Data suitable for different procedural techniques, evaluation, decision analysis, sensitivity analysis, criteria of choice.
Operational constraints (Constraints of operational feasibility and suitability)	(i) Agency type (ii) Resources of agency (iii) Powers of agency (iv) Political acceptability
Theoretical demands (demands for validity)	(i) Need for operational definition (ii) Need for data in suitable form for modelling, analysis and display (e.g. maps) (iii) Need for causality to be established.
Theoretical constraints (constraints of reliability and availability)	(i) Sampling techniques (spatial and temporal) (ii) Errors and uncertainty in defintion, measurement, prediction and forecasting; intrinsically probabilistic situations (iii) Data level (e.g. scale properties) obtained

Table 2.2 shows the full range of issues which ought to be treated in any truly comprehensive study of the research problem. The operational demands basically concern relevance and timeliness, in the provision of information appropriate to the particular stages in the planning process, to the particular type of evaluation or decision situation, and to

facilitate a sensitivity analysis of the procedures. Running through these issues is the question of whether the data are expressed in measures which truly reflect the issues of interest. The constraints on the development of an appropriate methodology are imposed by the nature, powers and resources of the agency by whom it is to be applied; for example the spatial scale of the County is greater than the District authority, or again the powers and resources of regional authorities may be more limited than Counties and districts; there may too be political factors which affect the formulation and operation of a methodology.

The key theoretical demands are the need for an operational concept and definition of the measured attributes, the form and scale properties of data, (for example the need for cardinal data in numerical weighting and arithmetic aggregation exercises), and the need for causality to be established in the development of theory, and in predictive, causal models. Theoretical constraints are chiefly concerned with the ubiquitous problem of errors which may enter at all stages in systematic scientific analysis, and in the appropriate (spatial and temporal) sampling of probabilistic and variable conditions, and the constraints imposed by the scale properties of the data on the valid mathematical manipulation and use (for example in quantitative evaluation techniques) of the information.

2.3.3 The Research Problem and the Conceptual Framework

As stated, Table 2.2 gives an 'ideal' framework of the issues which should be treated in the study of any given topic within the research problem area. These issues are a more systematic and general rendering of those key issues surrounding the research problem as shown in Table 1.2. Ideally the aims and objectives of the research should be moulded to respond to the full enumeration of the issues as given under the headings of the conceptual framework, but a cursory glance at the 'aims and objectives matrix' of Table 1.3 will show that the research actually responds with a heavy emphasis towards the theoretical side. This is because constraints of time and resources required that priorities be selected since a comprehensive response was unfeasible; priority was given to the development of a valid mapping methodology, and it must be emphasised at this stage that the operational issues may only be fully examined through an extensive range of further case studies in a variety of operational contexts, as recommended in Chapter 9.

Thus, most of the thesis is concerned with the theoretical issues in the development of the mapping methodology, the operational demands and constraints being restricted to the level of a broad discussion. Thus far the examination of operational issues has been limited to (i) the development of the conceptual framework itself, which has elucidated the nature of the issues but without reference to specific operational contexts, and (ii) the earlier discussion of potential policy applications of descriptive and predictive mapping methodologies given in Chapter 1.1. Maintaining the argument at the level of broad discussion, the analysis of particularly operational issues may be concluded with the summary, given in Table 2.3, of the suggested applications of the mapping methodology to the various stages in the planning process.

The role of the proposed mapping methodology is subdivided into three distinct functions, termed descriptive, analytical and predictive, and the Table shows the most potentially fruitful applications of each function in the five stages of the planning process. In addition a general distinction is made between those applications which fulfill the responsive (R) and promotional (P) components of local authority action. From the Table as a whole it may be observed that the mapping methodology may assist a wide range of planning stages and actions in an extensive variety of ways.

Table 2.3 Role of the Mapping Methodology in the Planning Process

Stages in Planning Process / Role of Mapping Methodology	Identification of Problems	Generation of alternatives	Evaluation	Implementation	Monitoring
Descriptive	Stress and Problem areas (P , R)	No-change Situation (R)	Baseline Pattern (P, R)		Shifts and trends in pattern (P)
Analytical	Factors causing stress and problem areas (P)	Pollution-minimising patterns (through causal knowledge) (P)			
Predictive	Prediction of new/future stress and problem (P, R)		Prediction of pattern for different alternatives (P)		Prediction of changes due to known or unplanned events (P)

P - Promotional action by LA, e.g. Structure planning, land use planning, 'potential surface analysis', environmental programmes. Specific objective to mitigate or minimise environmental stress.

R - Regulatory action by LA, e.g. development control, environmental impact analysis. Negative or optimising action in response to initiative by developer.

2.4 CONCLUSION TO THE RESEARCH CONTEXT

The establishment of the conceptual framework for the research concludes the discussion of the research context. The first two chapters of the thesis have considered the research context in two stages. In Chapter 1 the object was to establish the key issues of the research from a brief outline of the general policy and theoretical issues, and a discussion of the principal elements in contemporary research. Chapter 2 has taken the discussion to a more abstract and conceptual level with the aim of broadening the contexts and achieving a general framework for the research problem area. From this it has been possible to give a more systematic account of the factors influencing the direction of the research, both in the discussions of the theoretical and operational contexts in sections 2.1 and 2.2, and in the summary of the theoretical and operational demands and constraints derived from the conceptual framework. It was seen that the research was able to make only a partial response to the comprehensive range of theoretical and operational demands and constraints. The emphasis of the research is seen to be on theoretical issues in the development of the mapping methodology. The next two chapters now explore more deeply the development of spatial theory from which the TAE methodology is seen to evolve.

CHAPTER 3

THEORY AND METHOD IN SPATIAL REPRESENTATION, AND THE BASIS OF THE TAE MAPPING METHODOLOGY

3.0 OUTLINE OF THE ISSUES

3.0.0 Summary

The foregoing two chapters have referred in general terms to the predictive mapping methodology adopted in this research, and its articulation through 'area based spatial prediction models' founded on the concept of the 'Typical Area Element' (TAE). This chapter comprises the core of the research theory, describing in detail the theoretical basis for the mapping method and the concept of the TAE. The description is given within the context of a general discussion of the theoretical and conceptual nature of spatial representation and of the influence of operational factors in implementing mapping methodologies, in order that the particular advantages of the TAE methodology may be emphasised.

The TAE methodology is seen to exhibit two key features; (i) the relationship between environmental conditions and the urban fabric; this constitutes the predictive element and facilitates theoretical knowledge of causal factors and aids spatially comprehensive mapping; and (ii) the representation of the relationship over regular grid square zones; this provides the particular means through which the relationship was tested and validated empirically and then formulated into a mapping methodology that could be conducted as an operational cartographic display technique.

3.0.1 Spatial representation; issues of analysis and display

The structure of the chapter reflects the fact that although the TAE formed the basis of the mapping methodology that was developed in response to the general operational context of the research problem, the concept was first derived in connection with a more specifically analytical approach to representing spatial environmental pattern. To understand this distinction it is necessary to note the differences in conceptual and practical approach that exist between those spatial studies with broadly operational objectives, (where spatial information acts essentially as an adjunct to further, policy-oriented purposes), and those with more specifically analytical objectives; (where spatial information is directed towards understanding and tracing the pattern of spatial conditions). The dichotomy largely follows the differentiation made in the broad discussion of spatial studies given in Chapter 1.3. The ultimate operational purposes of the TAE methodology are clearly more closely identified with the former class of studies, but the TAE itself, which provides the key mechanism for achieving the simplicity, versatility, standard expression and economical use of data that characterises the operational mapping methodology, originated as a concept through which the spatial pattern of urban environmental conditions was approached in an essentially analytical manner. Thus as intimated in Chapter 1.3, the resulting TAE mapping methodology reflects, to a limited extent at least, a synthesis of ideas from both types of approach.

This procedure is explained more clearly through reference to the diagram in Fig. 3.1. At the theoretical and conceptual level of study the issues affecting the two types of approach to spatial respresentation are clearly distinguishable. In general terms the analytical approach is motivated by the principal objective of tracing and analysing the spatial variation of a property as precisely as possible, with the aim of advancing theoretical and conceptual knowledge about the nature of the spatial variation. Applying this approach to the analysis of urban environmental pattern, section 3.3 shows that, upon the assumption of a hypothesised relationship between the environmental characteristics of an area and certain characteristics of the area's urban fabric, it may be concluded that 'natural zones'[1] of environmental conditions exist in co-terminous

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1. The concept of 'natural zones' is explained in section 3.2.

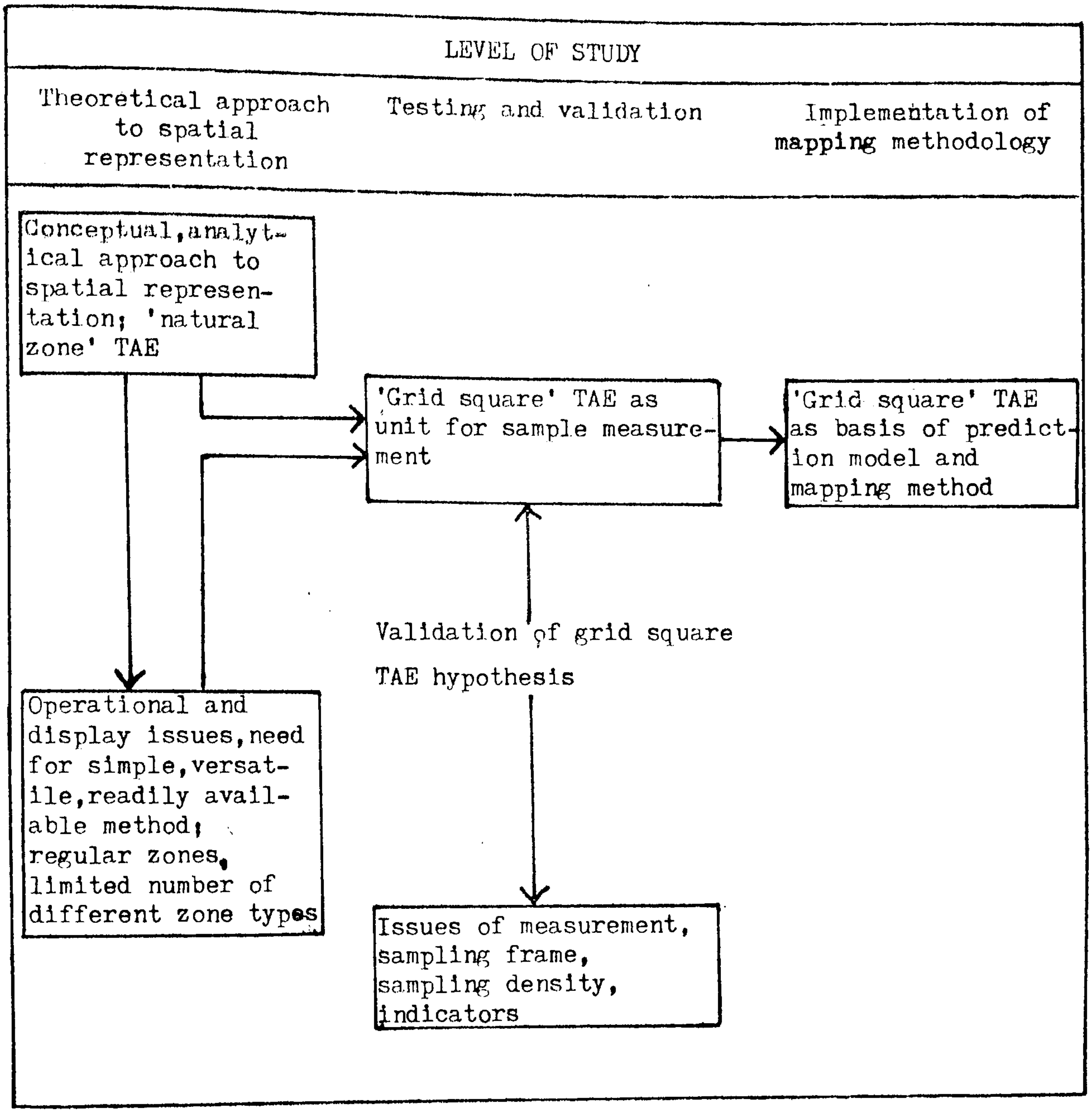

Fig. 3.1 Diagram showing conceptual 'sequence' in the development of the TAE mapping methodology

association with the distinct 'natural zones' which are known to exist in the urban fabric. Thus if these zones, termed 'Typical Area Elements', are designated over a study area on the basis of 'natural zone' divisions in the urban fabric pattern, a map of the environmental pattern may be predicted on the same spatial 'natural zone' configuration, given that the environment/urban fabric hypothesis is validated and expressed in a calibrated prediction model.

Spatial studies with broadly operational objectives however encounter a wholly different set of issues essentially oriented around the collection and display of spatial information. The need for a simple, cheap, easily obtained and operationally useful cartographic representation with readily informative visual content is of foremost importance. Other operational factors such as the need for the spatial and measurement resolution levels to be appropriate to the policy context and size of the study area, and the issue of data collection, must also be taken into account. Since the notion of the 'natural zone' TAE was developed without explicit reference to these issues it is necessary to reappraise the concept in order that it might respond to operational as well as analytical objectives. The result of this was the reformulated concept of the 'grid square' TAE, maintaining the same hypothesis but over a predetermined grid configuration of zones, and with other modifications to the consequent mapping methodology as described in the chapter 3.5. Thus as illustrated in Fig. 3.1 it was the 'grid square' TAE hypothesis that was tested and validated through empirical measurement in the research case studies and was subsequently applied in the form of a mapping method as explained in the chapter below. In this way a synthesis of both the analytical and operational approaches is achieved through the one methodology.

3.0.2 Synopsis of the Chapter

The above outlines the conceptual 'sequence' in the theoretical approach of the research to the demands of the research problem, and this is essentially the sequence of ideas as described in this chapter. To lay a foundation of current knowledge and technique in relation to the general issue of spatial representation, the chapter begins by summarising the main theoretical and conceptual issues in relation to spatial data, and proceeds in section 3.2 to discuss the range of mapping methodologies that have been developed to achieve cartographic representations of the patterns of spatially-distributed properties. It is seen that choropleth (zoning) maps are more appropriate to the research than isoline maps. Taking first the analytical approach as summarised above, section 3.3.

outlines the concept of the TAE as a method of achieving a 'natural zone' representation of spatial environmental pattern through the key environment/urban fabric hypothesis. The choropleth technique is reappraised in section 3.4 with respect to the operational factors summarised above, and the resulting reformulation of the TAE concept into a grid square mapping methodology is described in the concluding section 3.5

3.1 THEORETICAL AND CONCEPTUAL APPROACH TO SPATIAL DATA

This section discusses theoretical and conceptual issues in the analysis, measurement and representation of spatial information. This forms a necessary preliminary to the assessment of methods for mapping spatial data which follows in section 3.2. The main topics are seen to be the concept of spatial surfaces, the nature of point and area-based measurements, the spatial representativeness of observed data, and the methods of obtaining spatial data upon which a mapping method may be based.

3.1.1 The Concept of Surfaces

The research is fundamentally concerned with the investigation of the spatial distribution(or pattern as it is henceforth termed) of environmental conditions. An essential feature of this investigation is the assumption that these conditions exhibit spatial autocorrelation, in other words that the conditions described by any given observation are correlated with conditions holding over the immediately surrounding space.[1] From this assumption, which is validated both theoretically and empirically for most environmental attributes (see for example Chapters 5, 6 and 7), two critical concepts derive.

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1. The theory of spatial autocorrelation is described in detail by CLIFF and ORD (1973).

The first is that the pattern of conditions may be visualised conceptually as a 'surface', represented ideally by a three-dimensional mathematical equation with x, y spatial co-ordinates and a third z ('vertical') dimension representing the condition of the property under investigation. Conceptually therefore environmental conditions are seen "not as a morass of jumbled conditions scattered randomly through space ... but as comprising a form or pattern" (POCOCK 1977). Occasionally in environmental mapping the surface concept is used very explicitly as for example in the case of the trend surface analysis of air pollution concentrations (e.g. ANDERSON 1970) where quantitive mathematical equations describing the surface are formed; more often the concept is implicit, as in the case of any assumption that a single observation may be used to represent conditions over an area surrounding the place where the observation was made. This latter notion, proposing a degree of 'spatial representativeness' in single observations, is the second critical derivative of the concept of spatial autocorrelation and is discussed in 3.1.3.

3.1.2 <u>The Spatial Nature of Measurements and their Representation</u>

While conceptually the representation of an area's environmental conditions by means of spatial surfaces requires only that the conditions exhibit spatial autocorrelation, the 'surface' concept can only be effected through the use of the spatial data through which the conditions are described. Thus the spatial nature of the data will affect the spatial form in which the surfaces may be represented. Spatial data may be dichotomised into two forms, <u>continuous</u> and <u>discontinuous</u>; these types are principally associated with <u>point</u> and <u>area-based</u> measurements respectively.

Measurements which describe conditions at ideal 'points' in space are associated with the concept of <u>continuous</u> surfaces consisting of hypothetical observations located at all 'points' in space and separated by infinitesimal distance. A classical example is that of a topographical surface in physical geography; in the environmental field noise, air pollution and radioactivity are examples of attributes that may be considered in this way. Other parameters however are measured over units of area rather than at points, and many indicators and 'artificial' measurements are expressed in this form, for example population density, unemployment, and landscape quality. In each case a spatial unit is necessarily identified in the operational definition of measurement in order to specify the area over which conditions are to be assessed. In representing the spatial pattern of these measurements it is necessary to approximate the continuum of conditions (which may still hold in the abstract) to a discontinuous surface consisting of a pattern of discrete spatial units or 'zones', which may be regular - for example grid squares (e.g. SOUTH YORKSHIRE COUNTY COUNCIL 1978a) - or irregular, as in the case of local authority jurisdictions (e.g. WOOD et al 1974). Note that it may still be possible to conceive of an underlying continuum in the conditions of the property (in landscape quality for example), but the operational nature of the definition means that the spatial pattern of the conditions may only be represented by a discontinuous surface. In this sense the discontinuous surface is an approximation concept, and since the data of which it is ideally composed is less spatially precise than that of a continuous surface, it represents a lower level of spatial information. In some contexts (this research for example) it is however a more versatile form of information, and if necessary a continuous surface may be approximated or 'zoned' into a discontinuous surface.

This dichotomy in the conceptual basis of spatial surfaces is discussed further in section 3.2 when the mapping methods - through which the surface may be realised in cartographic form - are described. There it will be seen that there are essentially two kinds of mapping method; isolining (in which the surface is represented by a series of lines of equal conditions), and choropleth zoning (in which the surface is represented by a set of contiguous zones). These two representational techniques clearly mirror the conceptual dichotomy between continuous and discontinuous surfaces, but it will be seen that by transforming the data (of either type) it is possible to represent either of the two data types through either of the two mapping methods.

3.1.3 Representativeness of sample observations

It has already been stated that the notion of spatial autocorrelation is associated with the concept of spatial representativeness, in which the conditions observed at a single point may be considered representative of the conditions holding at surrounding points; and furthermore that area-based measurements may, depending upon the zone size and the scale of the spatial variability of observed property, be similarly representative of surrounding areas. The latter caveat in respect of area-based measurements makes implicit reference to the fact that the extent to which a single observation is representative of the surrounding area depends upon the extent and scale of the spatial variability of the conceptual surface. For example one might conceive of an homogeneous environment, like a desert, where a single observation may be representative of the conditions obtaining over an area of several hundred square kilometres over a timespan of years; the urban environment however is evidently more variable and a single observation will represent a much more limited area.[1]

It is clear however that the size of the area over which a single observation is considered 'representative' is dependent not only on the variability of the surface but also on the 'criteria of comparability', which are employed to distinguish between 'comparable' and 'different' observations and so clarify just what is meant by 'representative'.

1. This analogy, due to SAFEER (1973) is expounded in the specific context of ambient noise in Chapter 5.1.

These criteria, whatever they might be, effectively define an operationally-controlled resolution level in the metric scale through which the property of interest is measured. The 'criteria of comparability' themselves may depend upon a whole range of issues, theoretical, operational, and connected with the methodology of measurement, sampling and representation. Together these two factors, the spatial variability of the surface and the criteria of comparability of the observed data, control the size of the area over which the single observation may be considered representative.

This conceptual approach to representativeness gives a valuable basis to the discussion of sampling (see 3.1.4 following), and it also introduces the notion of homogeneity as being a key feature in the concept of zoning. This is evidenced in the way that, conceptually, the area over which an observation is considered representative forms a zone of space wherein conditions are taken to be homogeneous and equal to those described by the observation. The concept of within - zone homogeneity is an approximation for representational purposes and may be made despite full knowledge that variation exists within the zone.[1] This important issue is pursued in more detail in Section 3.2. It should also be noted that the 'zone of representativeness' is conceptually similar to the 'area-based measurement zone' since the latter also incorporates the same concept of within-zone homogeneity.

3.1.4 Sampling Issues in Spatial Measurement

It will be seen in section 3.2 that mapping methods may be applied to spatial data that can be obtained in two possible ways: measurement and prediction. In spatial measurement the two key issues are the sampling problems associated with temporal and spatial variations in the conditions

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1. This may even be quantified, for example in terms of a standard deviation - see the discussion of ambient noise in Chapter 5.

being observed. It will be seen in the relevant chapters that these were important problems in the empirical case studies.

(a) Temporal variation Thus far, the environmental surface has been treated as a 'static' concept. In reality of course many environmental attributes manifest conditions which vary over time as well as space, and a more realistic 'dynamic' conceptualisation would envisage a pattern which oscillates through time. The problem of representing spatial conditions that are temporally as well as spatially variable is complicated by the fact that cartographic representations are 'static' displays. The data displayed must therefore be temporally representative of some period of interest, i.e. temporal variation must be 'absorbed' into the data. The problem is similar in some respects to that faced by the climatologist who aims to represent the spatial pattern of temperature. With temperature varying both on a regular (diurnal or seasonal) cycle and also irregularly due to particular meteorological situations and in the short term over a single day, the climatologist seeks to monitor and measure temperature over a period in order to achieve a 'climatic indicator' of temperature, that is, a 'measure' of temperature representative of conditions obtaining at a given site over the 'climatic period' of interest (commonly a month, a season or a year). With temporally-variable environmental attributes it is similarly necessary to define an indicator with an appropriate 'climatic' period, such that the indicator-values for a given site are representative of the conditions obtaining at that site over the given time-period. Clearly there are two issues to be considered; (i) the type of 'climatic' indicator chosen, and (ii) the 'climatic period' that it represents.

Normally, 'climatic' indicators aim to represent the central tendency of the conditions obtaining within the given period, and are given by the mean or median condition. In some cases however the 'extreme value' approach is taken; for example in noise measurement the L_{10} represents the noise level exceeded for 10% of the sample period, and in air pollution studies indicators such as 'number of days exceeding threshold concentration x' or 'highest daily mean concentration per year' are sometimes used. The choice of indicator type is closely related to the operational purposes of the study. Chapter 2.1 referred to the need for measurements of the environmental 'stimulus' to correlate with human 'response', and it is the particular level of the response, whether it be to short periods of high stimulus, or long periods of low, 'background' stimulus, or to mean or 'typical' degrees of stimulus, that the various types of indicators reflect. In the case studies of the TAE mapping methodology it was broadly the 'typical' conditions that were reflected by the indicators chosen, since these are of the most general applicability.

The choice of an appropriate 'climatic period' is dependent upon the nature and extent of the temporal variation, and upon operational factors such as the method of measurement and whether indicators are determined from short-term samples or from continuous monitoring. As discussed in the context of the ambient noise case study in Chapter 5.1, it is possible to envisage a climatic period as comprising a 'population' of short-term sample conditions. Climatic indicators are therefore population parameters (e.g. the mean, or the upper decide in the case of L_{10}), and if these are to be estimated from short-term samples it is necessary for the climatic period to be chosen so that samples are random, independent and unbiased (as was the case in the ambient noise study); thus in such cases the climatic period should be chosen so that it is free of trends of cycles. Where continuous monitoring is possible these statistical requirements do not need to be observed, but for a climatic indicator to be meaningful and useful it is still necessary for climatic periods to be defined that show good replication. For example, in the climatological analogy, a given week in the calendar year is not useful as a climatic period because the mean temperature of any given week in the year is highly variable from one year to the next, owing to the random vagaries in meteorological conditions that occur over periods of a week or more. A seasonal (e.g. three monthly) or annual period is more useful because over such a period vagaries are averaged out and from one year to the next the replication in indicator values is therefore much higher. A principle which follows from this is that statistically significant variations in indicator values observed in successive equivalent climatic periods are indicative of substantive trends taking place in the 'climate' of the property in question.

In addition to these theoretical factors, it should be noted that considerations of operational feasibility - for example in data collection - will also act as criteria in the selection of an appropriate and practicable climatic period, as illustrated in the case of the sulphur dioxide study in Chapter 6.1.

(b) Spatial sampling density In comparison with the climatological analogy, the attempt to represent the environmental pattern through data measured at sample sites is faced with a more difficult task, due both to the short-distance spatial variation of some environmental conditions (for example ambient noise), and the fact that, pursuing the climatological analogy further, a conurbation or County, may encompass opposite extremes of 'climate' the equivalent of tropical and Arctic conditions.[1] Evidently therefore the analysis of environmental conditions requires a higher sampling density of observation sites than a climatological study. From the preceding discussion of the representativeness of observations (section 3.1.3) it is clear that the appropriate sampling density will depend on both the spatial variability of the conceptual surface and the operational issues which affect the required spatial and metrical precision in the data. As well as the demands of the policy context, these will be subject to the constraints of available resources for surveying and the feasibility of surveying an area the size of a conurbation or County.[2]

1. In fact urban ambient noise may exhibit the equivalent of these two extremes over a distance of some few hundred metres.

2. The operational issues are followed up in more detail in 3.4, and the general problems of sampling density and the location of sample sites in the context of specific attributes in Chapters 5, 6 and 7.

With this in mind it should be noted that while the earlier discussion of the criteria of comparability examined representativeness in an abstract context, the practicality of measurement and sampling imposes a further issue which an operational set of criteria must take into account.

3.1.5 Obtaining Spatial Data by Prediction

Prediction is the alternative method to measurement as a means of obtaining spatial data for mapping purposes. To be reliable, prediction must rely on a theoretical (causal or associative) foundation. Spatial data may be predicted from two principal types of theories: (i) point-receptor and (ii) area-based.

(i) In the point-receptor theories, the conditions obtaining at any given point in space are predicted from a knowledge of the location and intensity of relevant source-activities and of the manner in which the effects are transmitted from source to receptor. Examples are the theory of noise propagation from roads, as discussed by DELANEY et al (1971) and SOUTH YORKSHIRE COUNTY COUNCIL (1978b), and the various theories describing the dispersion of air pollution from sources to given sites as described in STERN (1968).

(ii) The area-based theories are founded upon the association of certain characteristics of a given area with the conditions to be found there; thus they deal with spatially aggregated conditions and source characteristics (for example the mean conditions over a unit of area), and do not involve a consideration of propagation except, in some instances, between-zone 'diffusion'. Examples are the association between types of area and typical noise levels, proposed in BRITISH STANDARDS INSTITUTION (1967, 1975), and the association between the characteristics of an area and its landscape quality, discussed by MANCHESTER UNIVERSITY (1976).

It should be noted that spatial prediction theories may be used in conjunction with the measurement techniques, for example in the Warren Spring Laboratory method of sulphur dioxide mapping (WILLIAMS 1978), and furthermore that the measurement techniques may be used to test, validate and calibrate the theoretical models as was done in this research. It is also evident that the point receptor theories involve spatially continuous assumptions about the predicted conditions, while the area-based theories are essentially 'spatial approximation techniques' expressed zonally. Conceptually therefore they are the equivalents of point and area-based measurements and consequently they are in general associated with the isolining and choropleth zoning mapping techniques respectively. From the foregoing chapters it will have been noted that the research is based upon the use of area-based theories in mapping, and this will be seen in the following sections of this chapter to be on of the key reasons for adopting the **choropleth** mapping technique rather than the isolining technique. Finally it will be noted that the above discussion of prediction methods makes no reference to the nature of the indicators predicted; however where the predicted conditions are temporally as well as spatially variable the need to identify 'climatic' indicators and periods applies just as in the case where the data are obtained by measurement.

This section has given a theoretical and conceptual basis to the understanding of spatial data. The concept of spatial surfaces has been described and it has been noted that mapping methods, through which the surfaces may be realised in cartographic form, require an input of spatial data that can be obtained by either direct measurement or prediction. Methodological problems in obtaining and expressing the data have been described, and it will be seen that these required detailed attention in the case studies (Chapters 5, 6, 7 and 8). It has been seen that the form of the data exercises some control on the range of possible mapping methods that a given set of spatial data may facilitate; this issue is amplified further in the following section, which also discusses the applicability of the various data types and mapping methods to the research problem.

3.2 METHODS OF MAPPING SPATIAL DATA

This section describes the methods which may be used to map spatial data. Mapping methods are seen to involve two component techniques: techniques for obtaining the spatial data, and techniques for representing the data cartographically. In the kind of study of which this research is an example it is seen that there are two principal alternative types of cartographic technique: isolining and choropleth zoning. The two types of technique are described in detail, and the spatial characteristics and scale properties of the spatial data to be mapped are seen to constrain the choice of a suitable technique. It will be seen that choropleth mapping methods are the most appropriate for the particular context and purposes of this research.

3.2.1 Mapping as an aspect of statistical cartography

Fig. 3.2 (due to DICKINSON 1973) shows that cartographic mapping may be seen as but one branch of an extensive taxonomy of the possible methods for displaying spatial statistical data. Following the course of the taxonomy it is evident that in the context of the research problem, (i) spatial distribution (i.e. pattern) needs emphasis, (ii) quantities are important, (iii) showing the quantities distributed within a given study area (e.g. the WMMC). Thus there are four possible representational techniques: dot displays, shading of zones, proportional shading of zones, and isolines. The other techniques that may be used (those designed more specifically for points) involve lower levels of information and are therefore less useful. Dot displays also involve the reduction of input data to a lower level of spatial information (in fact they require interval or ratio data but reduce the information displayed to a visual, qualitative level). Being therefore inefficient techniques for displaying spatial information they are normally used only where the visual effect or qualitative impression is the overriding purpose of the mapping exercise.

Fig. 3.2 Taxonomy of spatial statistical techniques for representing data. (Source: DICKINSON 1973).

Since shading and proportional shading are both examples of zoning, the available cartographic techniques may be reduced to two basic kinds:

(i) Isolining. The representational method involves the use of lines to represent the loci or 'paths' of points of equal conditions; an example is the topographical contour map. A continuous surface is represented and an estimate of the conditions obtaining at any given point in the study area can be achieved by interpolation.

(ii) Choropleth zoning. Spatial pattern is represented by the designation of the study area into a configuration of zones, thus representing a discontinuous surface. Within any given zone, conditions are assumed to be homogeneous, and therefore the method may be termed a 'spatial aggregation technique' since space is treated in aggregated units, and the spatial variation in conditions is represented cartographically only in terms of between-zone variation.

It will now be seen that the suitability of these two general types of cartographic technique to any given set of spatial data is governed by certain characteristics of the spatial data. It will be seen later (section 3.4) that operational factors are also significant.

3.2.2 Constraints imposed by Characteristics of the Data

It has been stated in section 3.1 that cartographical techniques provide a practical means for displaying spatial data. The same section stated that such data show either of two possible spatial characteristics; continuity or discontinuity. Evidently, as already seen , the former type is intrinsically more compatible with isolining, and the latter with choropleth zoning. However through transformations it is possible to adapt each data type to each of the representational techniques. Spatially continuous data may be adapted to the choropleth technique through 'approximation zoning' (see section 3.2 below), while spatially discontinuous data may be represented by continuous surfaces if these are regarded as 'potential surfaces',[1] that is surfaces showing a potential for certain levels of condition to obtain (WRIGLEY 1977).

The scale properties of the spatial data also influence its suitability to the two types of representational technique. Isoline surfaces may only be applied directly to data whose scale properties are at least interval. A data set manifesting nominal or ordinal properties may however be isolined as a 'probability surface' if it is transformed into a 'probability field' (WRIGLEY 1977), in which each data item describes the probability that a certain category of condition is fulfilled.

Nominal and ordinal data are however more easily mapped using the

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1. The cartographical term 'potential surface' implies no connection with the 'potential surface analysis' planning technique described in section 1.1.

choropleth technique. Nominal data may only be expressed in the simple ('category') shading of zones, as in denominational or national geographical mapping. In this case all that is required is to distinguish each zone from its neighbours and this may be done for example by an arbitrary range of colours. Ordinal data may be expressed by the proportional shading of zones (for example through a range of densities of lines or dots), but the information imparted must be understood to denote nothing more than the ordering of the categories. Interval or ratio data may permit either shading technique but the proportional method, in which shading can be used to signify the amount by which one zone's conditions differ from another's, is generally adopted since it carries more of the information available in the data.

In addition to these predominantly theoretical factors, both the isolining and the choropleth zoning techniques are influenced by operational factors. Essentially these concern the visual impact of the displays themselves and the extent to which the data displayed is of use in the relevant policy context. For example both techniques require that categories or intervals are defined in the metric scales upon which the data are measured, in order to limit the number of different lines or zone types that are represented. In addition the choropleth technique requires that operational factors are considered in the designation of appropriate sizes and shapes of zones. These operational and display-oriented issues are discussed in detail in section 3.4 in connection with the development of the TAE mapping methodology.

3.2.3 The Range of Possible Mapping Methods

In the foregoing it was made clear that there are in fact two components to any mapping method; firstly the technique for obtaining spatial data, and secondly the technique for representing the data cartographically. It has been shown that there are essentially two types of technique for obtaining spatial data; measurement and prediction; there are also two types of cartographical technique: isolining and choropleth zoning. Further, it has been shown that there are linkages which dictate the compatability of those component techniques that can together comprise a workable and valid mapping method. The following is a discussion, followed by an appraisal, of the range of the possible mapping methods that result from the matching of compatible component techniques. It was necessary in the research for this comprehensive classification of mapping methods to be made, in order to allow a method to be selected which was best suited to the research problem. The available methods are divided into isoline-based and choropleth-based methods.

(i) <u>Isoline-based methods</u>

These methods require that a regular, spatially comprehensive distribution of cardinal (i.e. interval or ratio) data, describing the conditions of the property to be mapped, be obtained for points distributed as regularly as possible within the study area. It was seen in 3.2.2 above that the isoline technique is only suitable for spatially continuous variables, or for discontinuous variables if 'potential' surfaces are obtained, for instance if it is assumed that the area-based data apply to <u>points</u> at the centre of the zones over which they were measured. The data may be obtained in two possible ways: (i) by direct measurement at the points in space (designated, for example, by grid nodes), or (ii) by the prediction of 'point-receptor' conditions using predictive models. As stated in 3.1.5, the latter method requires theoretical knowledge of causal or associative relationships, and cannot be applied unless the location of sources, their 'emission' strengths, and 'propagation' characteristics, are also known.

The simplest isoline-based mapping method is that of <u>manual isolining</u>, where the researcher draws a freehand isoline inbetween the data points, following the 'path' that, in his estimation considering the data available, is characterised by conditions equal to those given by the isoline value. In this instance the interpolation upon which an isoline is achieved derives from the intuitive knowledge of the researcher; it is possible in cases where the 'point-receptor' prediction technique may be used, for isolines to be determined from the prediction models alone giving a prediction isolining method, where the spatial pattern is the result of theoretically-based propagation and attenuation methods rather than interpolation.

Prediction is not the only alternative to intuitive interpolation however, for it is possible to conduct the interpolation through mathematical techniques involving statistical inference of the spatial pattern of point data. This is the principle of trend surface analysis (Chorley and Haggett 1965, Anderson 1970), where surfaces are represented mathematically by n^{th} order polynomials. The data at the sample data points are taken as the dependent variable measurements in a regression analysis through which the 'best fit' equation for a given polynomial of order 'n' is obtained. Various polynomial orders are attempted, usually varying from n = 1 (a simple 'linear' surface) to around n = 6, where the surface 'topography' is quite complex. The surfaces show the underlying trend of the spatial data appropriate to the given order n, and the researcher chooses the optimal n-value which shows a useful degree of spatial detail while keeping the 'prediction' error within acceptable limits. Where the original data set is ordinal and is transformed to 'probability' data, the same technique may be used, as in the probability surface mapping exercise of Wrigley (1977). A similar technique is that of empirical eigenvectors (Peterson 1970), through which a surface is obtained in terms of vector sets; four or five vector sets may usually be obtained which explain most of the observed spatial variance in the observed data. A less rigorous spatial analysis characterises the SYMAP technique, which is a computerised method for detecting the underlying spatial pattern in a spatial data set, through a process of spatially averaging the data sets obtaining within certain 'fields' of given points in space (DAVIES and ROBERTS 1976).

All isoline techniques rely on the assumption of a spatial autocorrelation in the data set - in fact the 'surfaces' of isoline maps amount to an explicit statement of the form of the autocorrelation. The extent to which these techniques may be used to provide meaningful surfaces therefore depends upon the extent to which autocorrelation is actually evident in the data, and in general it may be stated that the denser, more regular and more accurate the spatial data set, the more simple it is to detect this relationship. In these cases of highly detailed data therefore the simpler techniques, such as manual isolining or SYMAP, may be used; where the data is less complete, the relationship is less evident and consequently the more sophisticated techniques of mathematical analysis (trend surface analysis and empirical eigenvectors) are required.

(ii) Choropleth-based methods

The isoline-based methods have been seen to require point data, either obtained directly by measurement or prediction or indirectly by transforming area-based measurements or predictions into 'artificial' point data. Conversely, the choropleth-based methods are directly applicable to area-based data, but may also be applied to point data if this is approximated areally. Theoretically, the zone-based approach "can be regarded as part of the general problem of aggregation that arises whenever variables with continuous frequency distributions have to be grouped into discrete units for analytical purposes. It can also be viewed in terms of the development of typologies and classifications for spatial analysis, and as part of the general specification problem" (MASSER and BROWN 1978). The idea of representing environmental conditions by means of homogeneous zones describing the aggregate conditions of area units is quite common in contemporary research. For example, WOOD et al (1974) discuss conditions being "uniformly distributed within a particular zone"; the 'box-model' theory of air pollution dispersion involves the explicit assumption of the uniform within-box distribution of pollutants (e.g. GIFFORD and HANNA 1973; see

Chapter 6.2 of this thesis), while in the field of ambient noise too, SAFEER (1973) develops the notion of the "homogeneous sampling unit" as a representational basis.

The representational technique of zoning obviates the problems of interpolation that are encountered in isolining, but instead the problem of zone delineation is introduced. In fact the choropleth-based methods may be distinguished in relation to the theoretical and practical ways in which zones are designated. Arbitrary approximation zoning involves the imposition of a predetermined zone configuration upon the spatial data set. For example, zones may be delineated according to the boundaries of administrative jurisdictions such as boroughs or counties (e.g. Wood et al (1974)), or arbitrary spatial patterns such as grid squares, (e.g. South Yorkshire County Council 1978a). The procedure for mapping normally involves the aggregation of all data falling within each zone and the determination of a single 'representative' value or condition (usually the mean or median) which is then taken to characterise the whole zone. This approach applies equally to point and area-based types of spatial data. The method is arbitrary in the sense that the zone configuration is independent of spatial trends or patterns in the data. In the 'natural zoning' approach however, the spatial data are analysed for statistically significant spatial patterns which then form the basis for the delineation of zones. In this method therefore the data are used in the application of empirical or hypothetical criteria to determine zone boundaries. The theory of natural zoning derives from the general assumption that the factor which is of paramount interest, and therefore requires the strongest cartographical emphasis, is the pattern or spatial variation in the conditions.[1] In such cases, "a basic objective of zone system design should be to ensure

1. This is not of course true of all zoning contexts - for example electoral districting and traffic generation zoning both have the objective of minimising the variation between the conditions of individual zones.

that the amount of interaction (i.e. variation) that takes place within a zone is small by comparison with the amount of interaction between that zone and all other zones" (BROADBENT 1970). Thus the objective is to designate zones in such a way as to "maximise between-zone variation, in order to emphasise each zone's homogeneity and distinctiveness relative to the rest of the study area" (MASSER and BROWN 1978). These theoretical points were central to the development of the 'natural zone' concept of the TAE as described in the following section 3.3. Conceptually the theoretical approach is identical to that implicit in the ecological method of analysing the spatial variation in plant and animal species populations through the notion of 'clumping' or 'contagion' (GREIG-SMITH 1957, 1964, KERSHAW 1964). Although the ecological method uses only a limited type of data (the frequency of occurrence of a species per unit area), essentially the same 'natural zone' concept is utilised in an aggregation approach which determines the size of zone which most closely reflects the scale of the spatial variation.

As described here both the theoretical concept and the ecological example involve the statistical analysis of data as the basis for zone criteria, expressed in the aim of minimising the ratio of within-zone to between-zone variation. The disadvantage of this approach is that it is limited in applicability to contexts whose point data (or area-based data if the measurement zones are considerably smaller than the scale of the 'natural zones') are available on a spatially comprehensive basis for the whole study area. Furthermore it is necessary for the data to be expressed on cardinal (i.e. interval or ratio) scales, since parametric statistical techniques (i.e. the comparison of variances) are used to determine the optimal delineation of zones. As an alternative to the statistical approach however, it is possible to designate natural zones on a hypothetical basis. This 'hypothetical' approach is an example of the particular use of area-based prediction as the technique for obtaining the spatial data, and will be seen in section 3.3 to have formed the basis of the 'natural zone' TAE concept from which the TAE mapping methodology was derived. The method will be described in the above mentioned section in some detail; the essential principle is that 'natural zones' in the conditions of interest are designated co-terminously with 'natural zones' which are known or assumed to exist in the spatial pattern of a variable (or variables) with which the conditions of interest are hypothesised to be correlated. This system has several particular advantages, again described in detail in section 3.3; it can be used in cases where the conditions of interest may only be expressed in ordinal-scaled variables (a common occurrence in environmental measurement, as with landscape attractiveness for example). Moreover it is not necessary to measure the conditions of interest at a spatially comprehensive level since measurement is only required for the purpose of validating the hypothesised relationships, a procedure that may be conducted on the basis of measurements obtained in a limited number of sample areas (the method assumes of course that the predictor variable data are available at a spatially comprehensive level so that a spatially comprehensive prediction may be achieved).

In summary, the various types of mapping method available to spatial environmental studies in general are as follows (their relative merits in respect of the research problem are discussed in the section 3.2.4 following):

Isoline-based methods, generally requiring cardinal-scaled data expressed at points regularly distributed throughout the study area. Five types are available:

(i) manual isolining,

(ii) prediction isolining,

(iii) trend surface analysis (and probability surface mapping),

(iv) empirical eigenvectors,

(v) SYMAP

<u>Choropleth-based methods</u>, more flexible in data requirements:

(i) arbitrary approximation zoning (from spatial approximation of ordinal or cardinal point data),

(ii) arbitrary approximation zoning (from arbitrary measurement or prediction zones with ordinal or cardinal data),

(iii) 'natural zoning' (from statistical analysis of between-zone and within-zone variance of cardinal data),

(iv) 'natural zoning' (hypothesised from natural zones known to exist in a predictor variable pattern; validation and calibration possible on ordinal or cardinal data).

3.2.4 Applicability of the Mapping Methods to the Research Problem

Having described the principles of the available mapping methods it is now necessary to assess their applicability to the research problem. This may be achieved through reference to a set of criteria relating to the appropriate and necessary requirements of a mapping methodology that might respond to the needs of the research problem. These are derived from the issues examined in sections 1.3 and 1.4 and summarised in section 1.5.1.

(i) It is necessary for the method to be applicable to both ordinal and cardinal scales of spatial data, since a general mapping methodology must treat environmental attributes measurable on either type of scale.

(ii) The method must be applicable to both point and area-based data, since both spatial types of environmental data are encountered.

(iii) The method must allow the comparison of data to be achieved in a simple and readily comprehensible way. This applies both to the comparison of the overall patterns of different indicators over the study area as a whole, and to the comparisons of the conditions of a single indicator as between one part of the study area and another (such comparisons are necessary in planning contexts).

(iv) It must be possible for data to be aggregated both over space and over a range of indicators for a given part of the study area (such aggregations are necessary in planning contexts where for simplicity and impact it is necessary to condense detailed information).

(v) The method must utilise the results of area-based spatial prediction models, since these are useful in the examination of causal relationships that are of interest in the planning context, especially relationships between environmental variables and parameters which may be controlled or altered by planning policy decisions.

This list is not exhaustive, and it is predominantly the theoretical issues that are emphasised because at this point the purpose is to eliminate the mapping methods which are invalid in certain of the theoretical contexts of the research problem, or are unable to respond to particular theoretical requirements. Section 3.4 discusses several further (chiefly operational) issues, particularly those concerning the cartographic display of spatial data, in the final stage of the selection of an appropriate mapping methodology.

Firstly it will be observed that on the basis of the above criteria, the choropleth-based methods are better suited to the research than the isoline-based methods. This is so despite the fact that the isoline-based methods allow a more spatially precise analysis and depiction of spatial pattern to be achieved than is possible with the choropleth-based method, which rely intrinsically upon spatial approximation. In effect the analytical superiority of the isoline-based methods is outweighed by the restrictions in the types of data required and the difficulties in obtaining enough data to allow interpolation to be undertaken. By contrast the choropleth-based methods can more easily accommodate the lower-level (i.e. ordinal) scales of data and are as readily applied to point as to area-based data. Furthermore the comparison and aggregation of indicators is facilitated by the areal expression of the data; in fact it is not possible for comparison and aggregation to be achieved in a simple and readily comprehensible way for spatial data unless it is undertaken specifically with respect to units of area, i.e. clearly-defined zones. In addition, choropleth-based methods have been seen to accommodate area-based prediction methods either through approximation zones, or 'natural zones' in the pattern of the predictor variable(s).

From this appraisal it may be concluded that a choropleth-based mapping method should be adopted in response to the research problem. From the above descriptions of the available types of this method it is evident that the 'natural zoning' approach is the more analytically precise in that it allows spatial pattern to be represented with the greatest spatial accuracy and fidelity to the pattern which exists in the data. All things being equal this would therefore be the preferable method for use in the research (sections 3.4 and 3.5 show however that when further operational factors are taken into account it becomes preferable to adopt a grid square approximation zoning method). A comparison has already been made between the statistical and hypothetical techniques for conducting a 'natural zoning' apporach, and it was concluded in relation to the research that the hypothetical (i.e. area-based prediction) approach was preferable because, (i) it is markedly less demanding on the spatial comprehensiveness of the environmental data, replacing the need for regular and spatially comprehensive data by the need only for sample data upon which to test the hypothesised relationship, (ii) it allows the method to be extended from cardinally-scaled variables to include ordinally-scaled variables, and the extent of the necessary statistical analysis exercise is considerably reduced, (iii) it allows the hypothesised relationships between environmental conditions and the urban fabric (a highly important hypothesis in the urban planning context) to be tested, and indeed used as the basis of the mapping methodology.[1]

The following section describes the articulation of this proposed 'natural zone' mapping methodology through the concept of the 'natural zone' TAE.

3.3 THE 'NATURAL ZONE' TAE AS THE BASIS FOR A POSSIBLE MAPPING METHODOLOGY

The concept of the 'natural zone' TAE represents an essentially analytical approach to the mapping of spatial environmental pattern. The concept is first summarised and then discussed.

3.3.1 Summary of the 'natural zone' TAE Concept

The 'natural zone' TAE concept was founded upon a hypothesised relationship between environmental conditions and the urban fabric.[2] The relationship is manifested in the two key elements of the concept. The first of these concerns the way in which the 'natural zones' in the environmental pattern are spatially designated - that is, the way in which zone boundaries are delineated. A delineation is made with respect to the urban fabric characteristics rather than environmental data, on the assumption that 'natural zones' exist in the spatial pattern of the urban fabric (see the discussion below for a justification of this assumption). A concomitant of this is that (since 'urban fabric' is a nominally-scaled variable) the range of urban fabric conditions in a study area may be classified into a

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1. As already stated, it was not the 'natural zone' form but the 'grid square approximation zone' form of the hypothesis that was actually tested in the research - see section 3.5.

2. At this general level, 'urban fabric' may be understood to comprise such factors as land use, urban density, traffic density, population density, etc. The specific expression of the urban fabric through measurable parameters is discussed in Chapter 4.2

limited set of urban fabric types existing in association with the distinct 'natural zones' in the urban pattern. For example a 'residential area' is a distinct type of urban fabric and is commonly clearly delineated in the urban pattern. The second element of the concept involves the hypothesis that each of the urban fabric types is related to a 'typical' environmental condition, so that the 'natural zones' in the urban fabric are associated with co-terminous zones in the pattern of environmental conditions. These zones therefore correspond to recognisably distinctive spatial environmental units or 'Typical Area Elements' (TAEs) in the urban environmental pattern. Given therefore a spatially comprehensive base map of the urban fabric of a study area expressed in terms of contiguous 'natural zone' TAEs, it is possible to achieve a spatially comprehensive map of environmental conditions by transposing the data describing each zone from an urban fabric 'TAE type' to a typical environmental condition. For this to be possible it is necessary for the hypothesised relationship between environmental conditions and the urban fabric to be validated and expressed in a calibrated model relating TAE types to their typical environmental conditions.

3.3.2 Discussion

The previous section 3.2 showed that all mapping methodologies involve two principal components: (i) the obtaining of spatial data describing the conditions of interest (a measurment or prediction problem), and (ii) the representation of the data through cartographic techniques (a spatial and display problem). In relation to these it was seen that the statistical approach to the 'natural zoning' of environmental conditions is confronted by serious methodological difficulties, firstly in the obtaining of a spatially comprehensive set of environmental data at a sufficiently high sampling density to allow statistical analysis to be made, and secondly in the performing of the statistical analysis itself upon which the spatial 'natural zoning' system may be based. Furthermore the data quality necessary for the statistical analysis prevents any application of the method to ordinal data and to area-based data where the measurement zones approach the size of the 'natural zones'.

The foregoing has described an alternative approach that may be termed a 'natural zone' TAE mapping methodology, utilising the principle of the 'area-based spatial prediction model',[1] and it is evident that its chief advantages lie in the simple methods through which the problems encountered by the statistical approach are transcended. In relation to the first of the two principal mapping problems the need for extensive, spatially comprehensive environmental data for a study area does not apply since the comprehensive spatial coverage of a study area is achieved from urban fabric rather than environmental data; as will be seen in the following Chapter 4, the urban fabric may be expressed through parameters the spatial data for which are readily available to most local authority planning departments. Environmental measurement itself is reduced to a limited number of sample areas sufficient to allow validation and calibration of the hypothesised relationship between urban fabric TAE types and environmental conditions.[2] The second, cartographical, problem involving the designation of zones is again approached with respect to the urban fabric data, and the extensive statistical analysis of environmental data for zone-designation is replaced by the simple, direct use of 'natural zones' pre-evident in the urban fabric pattern, as discussed below. The method can be extended to ordinal data, and to area-based data for measurement zones up to the size of the 'natural zones'. This is possible because of the reduced dependence of the methodology upon statistical analysis. It was stated that a concomitant of the 'natural zone'

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1. Area-based spatial prediction models were discussed in section 3.1.5.

2. Using the same principle in the case studies of this research for example, only some 7% of the total WMMC study area was surveyed.

TAE concept was that the nominal-scaled urban fabric parameter should be classified into a limited number of 'types' ('TAE types'). As a result, the hypothesised environment/urban fabric relationship amounts to a proposition that the variation in environmental conditions between zones of different TAE types is statistically significantly higher than the variation amongst zones of the same TAE type. Not only can this hypothesis be tested non-parametically (i.e. on ordinal-scaled data) but individual zones may be (though are not necessarily) treated as indivisible, homogeneous spatial units (i.e., as single area-based measurement zones).

The conceptual nature of 'natural zone' TAEs is that they exhibit recognisable qualities of comparability within themselves and distinctiveness between themselves, such that they may be understood as typical (owing to the property of recognisable internal consistency) and individual (owing to their property of being clearly distinguishable from zones of a different type). Thus the 'natural zone' TAEs may be summarised as exhibiting the essential properties of within-comparability and between-distinctiveness; these qualities were seen in the general theoretical discussion of section 3.2.3 to be the principal features of the 'natural zoning' approach to choropleth mapping.

The summary of the method has referred to the dependence of the 'natural zone' TAE concept upon the presupposition that 'natural zones' do indeed exist in the pattern of the urban fabric. Considerable evidence, of theoretical, empirical and intuitive substance, exists to support this assumption, within the UK at least. In fact the theories of urban zoning date back to the celebrated 'Chicago' model, depicting annular zones of social activity in freestanding cities (BURGESS 1929), and even earlier to the historic models of 'utopian' cities. As argued by KENDIG (1976), "this approach posits that urban society differentiates into 'natural areas' (sic) which are 'territorial units whose distinctive characteristics - physical, economic, and cultural, are the result of ... ecological and social processes'" (attrib. to Burgess).

Contemporary urban systems clearly evidence the interplay of natural, economic, and planning forces, resulting in a discontinuous pattern of the urban fabric as represented by certain distinct types, combinations and associations of urban activity. This resulting zonal pattern has been examined in detail for Birmingham (JURUE 1977a), and has been the subject of wider study in the fields of urban geography and economics - as for example in the microeconomic theories involving land zoning, land rent theory and accessibility, discussed in MILLS (1972), BALCHIN and KIEVE (1977) and EDEL and ROTHENBERG (1972). Clearly however the hypothesis that 'natural' environmental zones exist in co-terminous association with the demonstrably-evident 'natural zones' in the urban fabric will only be validated if the urban fabric is defined in terms of urban fabric parameter categories that are indeed related to the spatial variation of environmental conditions. The purpose of the following Chapter 4 is to reformulate the evidence of contemporary research in order to develop such an urban fabric classification system.

As discussed in the remainder of this chapter however it was not the 'natural zone' TAE but a modified form of the concept expressed in grid square 'approximation zones' that was used and tested as the basis of the TAE mapping methodology. The value of the above discussion of the 'natural zone' TAE lies in the development of the concept itself in the context of an analytical approach to the representation of spatial environmental pattern. The following section 3.4 demonstrates the need in this research context to modify the purely analytical approach in response to operational and cartographical display issues; while this results in the substitution of standard grid square approximation zones for the irregular and variably sized 'natural zones'as the cartographical basis of the methodology, it will be seen in section 3.5 that the theoretical basis of the 'natural zone' TAE concept remains essentially unchanged.

3.4 OPERATIONAL AND CARTOGRAPHIC DISPLAY ISSUES IN SPATIAL REPRESENTATION

In the introduction to this chapter it was stated that there is a distinct difference between those mapping methodologies whose principal purpose is analytical and investigative, and those on the other hand which are motivated primarily by operational and planning-oriented contexts. It was also stated that this chapter would conduct as far as possible a separate appraisal of these two types of issue in relation to their influence upon the mapping methodology developed in response to the research problem. Thus the 'natural zone' TAE concept was developed under the premise that the underlying objective was analytical, i.e. to represent the actual spatial pattern of environmental conditions as precisely and faithfully as possible. This section now discusses the considerable range of issues neglected in a purely analytical approach to mapping but which must necessarily be taken into account if a mapping method is to be developed that is versatile, simple, useful and practicable in the operational planning context. These issues concern the visual display technique, and operational factors such as the spatial and metric resolution levels appropriate to the policy context and size of study area, and the problem of data collection. These are discussed below in the broad context of the choropleth-based methods in general, since the priority given at the end of section 3.2 to 'natural zoning' was based purely on the analytically-oriented criteria of spatial precision and fidelity.

3.4.1 Classification of Zones for Visual Display Purposes

Whatever the configuration of the zoning system that may be used to represent spatial data, each zone within a study area will possess a number or rank describing its general environmental condition. For cartographical display purposes it is necessary to visually identify (e.g. 'shade') zones in such a way that their range of conditions is represented. Because choropleth zoning is a spatially disçontinuous method of representing spatial variation, the cartographic representation of differences in the condition of zones may only be achieved with respect to discrete categories in the scale upon which the measurements of condition are made. Conceptually this involves the use of a 'resolution level' in the measurement scale in order to aggregate or group the range of different zone conditions that are assumed at this conceptual level to be distributed on a continuous metric[1] scale. As seen shortly, it is necessary to reduce the number of distinct measurement categories through which the variation in zone conditions is represented, to a number which can be clearly or 'readably' distinguished on a choropleth map - even though this represents an increasing loss of information or discrimination between the condition of individual zones.

DICKINSON (1973) has suggested various methods for this "interval grouping" of metric scales for display purposes. These are as follows:

(a) Simple division of the measurement scale through a process equivalent to the simple widening of the metric resolution level that appertains to all measurement scales.

(b) Quantiles, in which measurements are grouped with respect to their cumulative frequency distribution along the measurement scale.

(c) Standard deviations, in which measurements are grouped in units (or part units) of the standard normal deviate of their distribution along the measurement scale.

(d) Other mathematical intervals, such as geometric or logarithmic intervals.

(e) Natural[2] grouping, where the distribution of zone measurements along the measurement scale is grouped on the evidence of apparent natural clustering or natural 'breaks' in the distribution (for any given

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1. To avoid confusion over the term 'scale', measurement or 'metric' scales are explicitly distinguished from 'spatial' scales.

2. Not to be confused with 'natural zoning'.

number of 'groups', this method minimises the information loss that is consequent upon grouping, as discussed by THEYS 1976).

It should be noted that since the isolining technique involves the display of a discrete number of lines on a map, it too necessitates the metric scale of the spatial data to be grouped into discrete intervals. In the case of the isolining technique there is no particular reason why the number of intervals (and, therefore, isolines) should be restricted, except in that the accuracy of the data imposes a maximum 'resolution level' threshold, and operational considerations of representational convenience or economy may be important. Indeed, the general criterion for giving the maximally informative spatial pattern is to decrease the intervals (and, therefore, increase the isoline density) as much as possible, suchthat the representation tends to a spatially 'continuous' illustration. Where the choropleth technique is used however, there are clear practical issues which limit the number of intervals or categories of conditions which may be represented, and these issues are supplemented by the question of data accuracy (which also constrains the precision of the isolining technique). Naturally a 'readable' choropleth map must allow a visual distinction to be evident between the individual categories or intervals represented, and the technical limitations imposed by human perception and graphical methods (e.g. proportional shading of zones) mean that choropleth maps are usually limited to the use of between five and seven class intervals to produce a map that is 'readable' (GORDON 1978). Gordon's typical range of interval numbers is borne out by the evidence of most environmental studies - for example, WARREN SPRING LABORATORY (1974) use four class intervals, WOOD et al (1974) use five, CHESHIRE COUNTY COUNCIL (1977) use both four and five and SOUTH YORKSHIRE COUNTY COUNCIL (1978a) use five; in (1978b) the same authors attempted to use ten but found in general that neither the display techniques nor the accuracy of the data were able to support this amount of detail.

In the empirical case studies it was decided to use five class intervals or categories of conditions in the mapping process, each category consisting of a group of TAE types. The number five was chosen because it was thought to be feasible to obtain data to allow five distinct categories to be defined, and to use a graphical technique to allow these groups to be distinguishable on a choropleth map, and also because that number was typical of many contemporary environmental studies.

In the technique for grouping the TAES the natural grouping method was preferred since, as stated, it minimises the amount of information that is lost through grouping; however it was also considered necessary to maintain wherever possible a consistent urban fabric identity to the groups of TAE types, and the relevant sections of each of the case study chapters (5.5, 6.5, 7.4, 8.3) describe how in each case a grouping method was conducted that reconciled these two criteria.

3.4.2 Zone Delineation: Choice of Configuration Type

The visual information imparted by a mapping method is obviously important in operational contexts where the information acts as the source or baseline for other operational (e.g. planning oriented) purposes. It will now be seen that in choropleth maps the amount of information imparted is determined by the shape (configuration) and size of the zones. In addition to the issue of visual information, zone shapes and sizes may be determined by other operational factors affecting the data - for example the prime purpose may be to represent the differences in conditions between local authority areas, in which case the jurisdictional boundaries will be used to delineate zones; or again it may be that data are only available for jurisdictional zones, as was true of the study by WOOD et al (1974). These are examples of 'approximation zoning', where in contrast to 'natural zoning', zones are delineated arbitrarily with respect to spatial pattern. Despite reflecting spatial pattern with less analytical accuracy and spatial precision, approximation zones are frequently more relevant, useful or feasible in the operational context. Moreover in cases where there is no statistical or hypothetical foundation for 'natural zone' delineation, they constitute the only possible zoning method.

All things being equal, it is obviously preferable to represent pattern in a way which imparts the maximum visual information, and also to produce a cartographical form that is easily compared and aggregated with other maps. In this respect there is a clear preference for grid-square zoning. This conclusion is based on established theoretical arguments described below.

The theoretical criteria determining the most visually informative size and configuration of zones have been investigated by several workers; BATTY (1978) has concluded that "given any number and configuration of zones (over the study area), the resulting system manifests an amount of detail concerning the phenomenon of interest which is hereafter referred to as information. As the number and configuration change, so does the amount of information which is transmitted to any observer; and ... the greater the number and more regular the configuration, the greater the information imparted." The need to maximise the number of zones per unit area (and therefore to minimise individual zone size) is obvious, since each zone constitutes an individual unit of information and therefore the total information imparted by a zoning system over a given study area is increased as the number of zones increases. The need for a regular zone configuration derives from the statistical demand for equal zone sizes; "equal areas imply that equal weight is given to each spatial unit ... so that space should act on the analysis in a neutral way" (BATTY and SAMMONS 1978). In the aggregation, analysis and comparison of zones of unequal size, weightings must be applied to neutralise the differential effect of space and the process can be complex (ROBINSON 1956). Thus, "the best approximation that could be made to the underlying density (i.e. pattern) would contain as many zones as possible and would be based upon a regular, systematic partitioning of the space into zones whose theoretical form would be hexagonal" (since the hexagon is the most efficient form of two-dimentional spatial packing; BATTY and SAMMONS 1978). Square-shaped zones however provide the simplest method of regular contiguous zoning since they may be designated and identified through a normal, simple grid-square system using rectangular Cartesian co-ordinates. Furthermore they facilitate regular spatial aggregation between zones (as in the operation of the ecological 'clumping' analysis), and allow interactions between zones to be simply represented (as for example in area-based air pollution dispersion modelling; see chapter 6.2). Consequently the operational, display-oriented approach finds a preference for this type of regular zone configuration. The theoretically-derived demand for "as many zones as possible" is constrained however by a number of factors concerning zone size which are now discussed below.

3.4.3 Optimum Zone Size

From the theoretical discussions of representativeness and the criteria of comparability in 3.1.3, it was seen that a variety of issues affect the choice of an optimal zone size over which to depict representative and assumedly homogeneous conditions. From a theoretical viewpoint, BATTY (1978) has been quoted as holding that zone size should be minimised in order to maximise the transmission of information. In the context of this research, this rationale is offset by other factors which limit the minimisation of zone size; these may be classified as (i) theoretical, and (ii) operational and display issues.

(i) Theoretical issues

A fundamental component of the research has been identified as the investigation of the relationship between the pattern of environmental conditions and the pattern of the urban fabric, and as described in Chapter 4 below, an area-based approach is taken in this study. In principle this approach attempts to relate the environmental conditions within a zone to the nature of the urban fabric within the zone[1], and a condition of this analytical approach is that within-zone conditions are not significantly affected by factors operating or obtaining outside the zone (the condition of 'functional zone independence'). The propagational nature of some environmental attributes, for example air pollution and noise, mean therefore that there is a lower limit to the possible size of zones if this condition is to be maintained. Wood has recognised this in his view that, "because of transfers between zones, the subdivision (of the study area) should not be so fine that those transfers become more important than the pollution process within a particular zone" (WOOD et al 1974).

In this context there are at the same time theoretical factors which limit the maximum possible size of zones, since as zone size increases the characteristic nature of the zone becomes increasingly heterogeneous both with respect to environmental conditions and the nature of the urban fabric, and distinctive zone identity is lost. From the theoretical viewpoint therefore, there is conceptually an optimal zone size which maximises the condition of 'within-comparability and between distinctiveness', a condition translated to regular grid-square zoning from the theoretical notion of the 'natural zone' TAE.

(ii) Operational and display issues

Synthesised with Batty's theoretical considerations of the display of information, there is seen to be a theoretical 'optimisation function' for the choice of an optimal mapping methodology zone size, which calls for the 'minimisation of zone size subject to the condition of functional zone independence'. Other operational and display issues affect the

1. Such was seen to be the conceptual basis of the 'natural zone TAE.

actual selection of zone size however. Some of these have already been identified; the form of available data may limit the minimum possible zone size, as was the case in the study by WOOD et al (1974), where local authority zones were used; and in other cases the operational need for particular zone boundaries like local authority jurisdiction may override all other factors. The limitation on the metric resolution level through 'grouping' of conditions also set up 'criteria of comparability' which limit zone size.

These three issues, the available data form, the metric scale resolution level and the operational need for a particular delineation of zones, may each effectively predetermine the zone size, in which case the theoretical 'optimisation function' approach is irrelevant. In circumstances where there is an option about the choice of zone size however, there are operational and display issues which must be taken into account in addition to the theoretical 'optimisation function' factors. These concern the fact that the operational policy context may lead to the choice of a particular degree of spatial resolution in the displayed data. In this case one might conceive of a conceptual spectrum of possible zone sizes ranging in the urban environmental context from large zones with wide internal variance in conditions (a single urban/rural dichotomy would be an extreme example) to small zones within which data would vary little over space (a street-block unit might be an example). From the operational policy viewpoint it is clear that the two extreme examples would give in the former instance almost no information at all, and in the latter instance a spatial maze of information where the trends and patterns of particular policy interest may be lost in the detail. In selecting the optimum zone size, the spatial level of the policy issue[1] is clearly an important

1. This is a function of both the area size (e.g. region, County or district) in which the policy is discussed, and also the requirement for spatial detail in relation to the policy issue itself.

factor; for example a regional policy context will generally require a lower spatial resolution level than a review of local plans in a district authority. The description of the conceptual spectrum of possible zone sizes also highlighted the fact that there is a linkage between zone size and the degree of zone homogeneity, and this brings to light the fact that the choice of optimal zone size may actually be determined in some policy contexts by the need for a certain metric precision in the data, rather than through the criterion of spatial resolution level. For example if for some purpose it was necessary to achieve a distinction between the ambient noise levels of zones on a metric resolution level of 2dBA, smaller zone sizes would be required than if, say, a 5dBA resolution level had been acceptable.

A complex range of operational and display issues may therefore contribute to and possibly dominate the actual selection of an optimal zone size. More generally, this section has shown that these issues require a considerable modification to be made to the original notion of the 'natural zone' TAE if a mapping methodology is to be developed which will allow these issues to be expressed, as indeed it must if it is to be an operationally versatile as well as analytically useful tool.

3.5 A MAPPING METHODOLOGY FOUNDED ON THE TAE

3.5.0 Outline

In section 3.3 the 'natural zone' TAE was developed as an essentially investigative approach to spatial representation, describing and analysing the natural pattern of environmental conditions with a minimum of artificial representation. This section discusses the reformulation of this approach into a more operationally useful mapping methodology responsive to the operational and display issues discussed in the previous section. The TAE concept is therefore adapted to these demands, the most significant modification being the approximation of TAEs to grid square zones.

3.5.1 The Concept of the Modified 'Grid Square TAE

The 'natural zone' TAE involved both a spatial and a metric approximation. Spatially, the environmental pattern was approximated to discrete, contiguous,assumedly, irregular 'natural zones'. It was also proposed that the metric continuum of zone conditions could be represented by a limited set of 'types' of condition. The discussion of the operational and display issues showed that in the research context further approximations must be made, both in spatial and metric terms:

(i) It is necessary to limit the number of different area types that are mapped to a level which is appropriate with regard both to the display issue of mapping and distinguishing the different area categories, and the measurement issue associated with the accuracy of the measurement scale given the problems of sampling and, in this case, prediction.

(ii) For display purposes the use of a regular zoning system is preferred; the simplest form of which is the grid square configuration; this configuration is especially amenable to spatial aggregation and spatial comparison and aggregation of different indices.

(iii) It is necessary to choose an optimal size of grid square zone, resulting from the consideration of a variety of theoretical, operational and display issues, these being principally, (a) the theoretical condition of 'functional zone independence', (b) the operationally appropriate spatial and metric resolution level for the given policy context and study area size, and (c) the underlying display demand for a minimised zone size subject to the appropriate display size for the operational context (however a major constraint on the actual use of a rationally-determined optimal zone size is the spatial scale of available data).

In response to these issues the following modifications to the concept of the TAE were proposed:

(i) That for representational and display purposes (though not for the purposes of testing the hypothesis and calibrating the area-based prediction model), the TAE types should be aggregated or 'grouped' to achieve a suggested limit of five categories of environmental condition; as discussed in 3.4.1 this accords with the kind of discrimination commonly used in large scale environmental studies;

(ii) that the delineation of TAEs should be made in the form of a regular grid square configuration of zones;

(iii) that a standard grid square zone size should be chosen from consideration of the various theoretical, operational, display and data-availability issues (to be described in detail in Chapter 4).

The adoption of a grid square unit for representational purposes is effectively a second stage of spatial approximation, and in terms of the classification of mapping methods presented in section 3.2 the TAE methodology becomes a normal 'approximation zoning' choropleth-based method. The hypothesised environment/urban fabric relationship is therefore no longer used as a means of zone delineation since an artificial grid square configuration is imposed a priori on the spatial pattern. Other analytical roles of the hypothesis are nevertheless maintained, namely the provision of a sampling frame to avoid sampling across the whole conurbation, and the subsequent provision of a predictive model so that a spatially comprehensive depiction of environmental pattern may be achieved. The function of the hypothesis in terms of enhancing theory and achieving a dynamic mapping model is weakened, in that the investigation of an environment/urban fabric relationship using grid square zones as the area-base provides a weaker test of the original 'co-terminous natural zone' hypothesis. What is in fact tested in the research case studies is not the degree of association between hypothetically co-terminous zones of environmental conditions and urban fabric types, but simply the degree of correlation between measures of environmental conditions and urban fabric types taken over common units of area for which it is assumed that the relationship is functionally independent of outside influences. However, because of the spatially more approximate nature of the latter relationship it may be inferred that if the latter relationship is indeed found to be statistically valid, it is even more likely that the original 'natural zone' hypothesis is valid.

3.5.2 Summary and Conclusions

It may be concluded, as illustrated in the introductory conceptual diagram in Fig. 3.1, that it is the reformulated concept of the 'grid square' TAE which offers the most appropriate means for responding to the research problem, and it was this concept which was tested and applied in the empirical case studies of this research. Henceforth therefore the term 'TAE mapping methodology' will be understood to refer exclusively to the mapping methodology derived from the grid square expression of the TAE concept. The environment/urban fabric hypothesis now asserts that the environmental conditions representative of regular grid square zones in the study area are related to certain characteristics of the urban fabric of such zones, where the zones are of a size that maintains their functional zone independence. The corollary of this proposition is that the classifying of the zones in a study area in terms of a set of urban fabric types will allow a statistically significant proportion of the total spatial variation in environmental conditions of zones to be explained. This puts the hypothesis into the form which was actually tested in the case studies.

The following chapter 4 describes the urban fabric classification system through which 'TAE types' were defined, and the rationale and methods through which it was derived from the evidence of contemporary research. The final, precise form of the TAE hypothesis and mapping methodology that was tested in the case studies can then be presented. Here, the key features of the TAE methodology are summarised below as a means of arguing the principal advantages of this particular approach. This is best achieved through reference to the relevant criteria for an appropriate mapping methodology to this research context that were given at the conclusion of chapter 1 (section 1.5). The various relevant elements in these criteria are referred to individually.

(i) The methodology allows spatially comprehensive coverage of a study area to be achieved through the 'area-based spatial prediction models' founded on the concept of the TAE - hence the impracticable task of measuring a large number of environmental variables over the study area is replaced by the more feasible proposition of calibrating the models upon data obtained in only a limited number of 'sample frame' areas.

(ii) The use of a regular grid square configuration of zones allows a standard spatial basis for the comparison of the patterns of a range of environmental variables, and also for the aggregation of a range of indicators and for the simple spatial aggregation of a given indicator pattern to larger units of area, for example the 'District' sub-units of a County.

(iii) The methodology is simple to operate since comparatively little statistical analysis is required and the models can be applied as mapping methods through the simple conversion of zone identity data to environmental data (the use of a computer is not essential).

(iv) The methodology is cheap to operate, mainly because of computational simplicity and because comprehensive spatial coverage is achieved from readily available (urban fabric) data.

(v) The methodology is versatile in that it is valid to apply it to environmental attributes measurable in either cardinal or ordinal data, with either point or area-based spatial characteristics (limitations in the general applicability are discussed in Chapters 4.1 and 9.2).

(vi) Causal factors determining the environmental pattern are examined and tested, and since these are also integrated into the mapping methodology through the prediction models a 'dynamic' methodology results, rather than the purely 'static' or descriptive maps that result from the use of measurement data alone.

CHAPTER 4

FORMULATION OF HYPOTHESES AND EXPERIMENTAL DESIGN

4.0 OUTLINE OF THE ISSUES

The theoretical basis of the TAE mapping methodology proposed in this research has now been established. The principal objective of the empirical case studies was to validate the hypothesised relationship between the environmental conditions and urban fabric characteristics of a regular grid square configuration of zones within a case study area. The results of the validation exercise could then be used to calibrate an 'area-based spatial prediction model' which then forms the basis of the proposed mapping methodology. This chapter sets out the explicit hypotheses and the experimental design for the case study approach to the validation exercise. Firstly, three environmental attributes are selected for study on the basis of criteria which ensure that their nature and the methodological problems they embrace are representative of the issues that would be encountered in a more environmentally comprehensive range of attributes. As stated in the preceding chapter, the hypothesis is expressed through the definition of a set of urban fabric types which are assumed, through hypotheses derived from contemporary research, to differentiate the range of the conditions of the selected attributes likely to be found over a large conurbation. The bulk of the chapter is concerned with identifying and classifying appropriate parameters of the urban fabric in order to achieve such a set of types; this then constitutes the set of TAE types that is tested as a differentiator of environmental conditions and applied in the mapping methodology through the case study approach. The chapter concludes by summarising the procedure through which the testing was undertaken using the West Midlands Metropolitan County as a case study area.

4.1 SELECTION OF ENVIRONMENTAL ATTRIBUTES

In considering the spatial representation of environmental conditions at the theoretical and conceptual level, the discussion has proceeded through allusion to the 'conceptual environmental surface'. In fact of course this 'environmental surface' has no physically measurable basis; it has been seen in earlier chapters that the concept of 'environment' consists of a composite of physical and qualitative attributes the identity, number and relative importance of which is not definable in any absolute sense, being critically dependent upon the context and purpose of any given study. Local authority planning has been identified as the central operational context of the research, and so it is necessary to select for the detailed case studies a range of attributes which are representative of the environmental issues, attributes and methodological problems encountered in local authority planning contexts.

4.1.1 Criteria for Selection of Attributes

Five requirements were used as the basic criteria in making the selection of attributes for the case studies. These are given as follows:

(i) That the total number of attributes selected should be small enough to ensure that the validation of the hypothesis is feasible given the limited resources, time and effort available in the research programme;

(ii) That the attributes selected should be measurable over the sample TAEs either through practicable field study or readily obtainable data;

(iii) That the types of attribute selected should be representative of those types that are of interest in the local planning context;

(iv) That attributes should be restricted to those which are 'ambient' over space;

(v) That the methodological problems of measuring and representing the selected attributes (with respect to the spatial type of measurement employed, the problem of temporal variation, spatial variation and sampling, and scale properties of the data) should be representative of those issues presented by the range of ambient attributes which are of interest in the local planning context.

4.1.2 The Choice of Attributes

From a consideration of these criteria, three environmental attributes were selected for detailed case study analysis:

ambient noise, sulphur dioxide air pollution, and area appearance[1] (detailed definitions are discussed in the relevant technical chapters when appropriate measurable indicators are identified).

The potential attributes for study are seen to be restricted to those exhibiting 'ambient' characteristics. The concept of ambience is applicable to those attributes whose condition is measurable at any point or area in space and is not usually identifiable with any single particular source. Two categories of non-ambient attribute may be identified, and are therefore excluded from the interest of this research. The first category applies to conditions which are only found in physically constrained areas of space. Water quality is the most obvious example of this type; building condition is another example since it only applies to those areas of space where there are buildings.[2] The second category includes conditions which, while not physically constrained as such, are only found over limited areas of space often near to particular sources; examples in this category are aircraft noise (localised near airports) and radiation hazard (localised near radio-active activities). The non-ambient attributes present a particular, different class of problem in terms of measurement and spatial representation for although it is possible that artificial area-based measures of non-ambient attributes may be designed, for example water quality (e.g. SOUTH YORKSHIRE COUNTY COUNCIL 1978, WOOD et al 1974), it is necessary to include in the measurement a response both to the representative condition of the attribute (e.g. river water quality) and the proportion of the area over which the attribute is measurable. This raises scaling problems which

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1. A qualitative, composite attribute describing the visual condition of an area.

2. The research does in fact consider a building attribute (building decay), but operationally defined in such a way that the attribute itself is ambient.

cannot be properly treated within this research, since the conceptual basis for the TAE involves the assumption of spatially comprehensive attributes. Thus it may be seen that the TAE methodology conceived of and tested in this research is limited in its generality to those environmental attributes which may be considered 'ambient'. This issue is discussed further in Chapter 9.2.2, where examples of the ambient class of attributes are listed, and it is seen that in fact an extensive range of attributes can be treated in this way. (Table 9.3)

The three selected attributes are small enough in number to allow a detailed study of each to be feasible, and the data through which the hypotheses may be tested are either obtainable through the development and conduct of field survey techniques or (as in the case of sulphur dioxide air pollution) through the manipulation of data available from secondary sources (see the relevant case study chapters). With respect to criterion (iii), it was stated in Chapter 1.1 that the range of attributes relevant to the local authority context could be classified into four categories comprising noise, air, water and land. Of these principal types it has already been made clear that the issue of water quality raises problems that are beyond the scope of the research. Ambient noise is identified directly as an attribute for this research; air pollution may encompass a number of pollutants, commonly sulphur dioxide and smoke or total suspended particulates, the traffic-related pollutants (carbon monoxide, oxides of nitrogen, hydrocarbon, lead) and industrially-related pollutants notably heavy metals and odours. The source-related pollutants are however not generally ambient in nature (but see the discussion in Chapter 5, section 5.6), and sulphur dioxide is frequently chosen as a pollutant representative of general air quality (e.g. SOUTH YORKSHIRE COUNTY COUNCIL 1978, MARSH and FOSTER 1967, PETERSON 1970, SHARMA 1975). 'Land' includes a variety of components; dereliction is common (e.g. MERSEYSIDE METROPOLITAN COUNTY COUNCIL 1976), but waste disposal and tipping (WOOD et al 1974), visual quality (PERLOFF 1972, SOUTH YORKSHIRE COUNTY COUNCIL 1978), and social aspects such as public open space (KARPE and SCHOLZ 1976), street quality (CIVIC TRUST 1971) and building condition (BUCHANAN 1973) are also featured. The choice of 'area appearance' as a composite parameter allows the interest in an area's visual condition to be represented. Together therefore this small selection of attributes reflects the broad areas of interest in the local government context. The methodological issues raised by criterion (v) are also well represented; ambient noise has a close spatial association with its many sources and is therefore highly variable over space; in addition it is highly time-variable. Sulphur dioxide diffuses more widely from its sources and is therefore less intensely space-variable; by contrast the variation in concentrations over time is less stable and predictable than with noise. Area appearance is (for the purposes of the research) constant over time, but presents different methodological problems from the other attributes through the subjectivity of the concept, the aggregate nature of the indicator and the ordinal, area-based nature of its measurement. Consequently the three attributes as a whole present a good cross-section of the methodological problems likely to be encountered by a spatially comprehensive mapping methodology.

Henceforth therefore the thesis is concerned with the specific investigation of the TAE mapping methodology in respect of these three attributes and Chapter 8 also discusses a possible method of aggregating individual attribute measures into an overall environmental indicator. Since the selected attributes are only a sample of the comprehensive range that is of interest in many operational contexts, and since many important non-ambient attributes are specifically though necessarily excluded from consideration, it must be emphasised that the research was only able to conduct a partial testing of the TAE mapping methodology; the significance of this in the assessment of the generality of the methodology, and its implications for further research, are discussed in chapter 9.2.

4.2 PRELIMINARY BASIS FOR THE DEVELOPMENT OF THE HYPOTHESES

4.2.0 Outline

Before giving a detailed statement of the hypotheses, it is necessary to clarify the nature of the hypothesised relationship, to quantify an appropriate grid square zone size over which to examine it, and to review the methods of classification used by other contemporary research.

4.2.1 The area-based relationship

In discussing spatial prediction theory as a method for achieving a spatially comprehensive representation of conditions, section 3.2.2 described the two alternative theoretical approaches, evidenced in the point-receptor and area-based models distinguished in section 3.1.5. Several important reasons were given for the choice of the area-based approach. The above criterion limiting the research to the 'ambient' environment provides a further important reason for this choice. This follows because the application of the alternative point-receptor approach would involve the designation of zones around particular source or emitter locations - for instance major roads, motorways, airports and industrial sites in the case of noise,[1] or power stations, industrial stacks, commercial centres and uncontrolled domestic areas in the case of sulphur dioxide; clearly such an approach would forsake the principal of 'ambience' under which it is taken that observed environmental conditions cannot generally be ascribed to any particular individual source. In addition, source-related zones would, if they were 'nested', transgress the condition of 'functional zone independence', and would in any case be difficult to designate meaningfully on a grid square configuration; furthermore it would not be possible to use a common zoning system for all three attributes. The area-based approach does not suffer these disadvantages, and moreover it is directly amenable

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1. The study by SOUTH YORKSHIRE COUNTY COUNCIL (1978b) suggests such a method.

to a theory for those indicators, such as area appearance, which are represented by area-based measurements.

4.2.2 Parameters used in Contemporary Research to Classify the Environment

The discussion of the TAE in the previous chapter made clear the fact that the hypothesised environment/urban fabric relationship is essentially expressed through the classification of urban fabric parameters which act as 'differentiators' of environmental conditions. Moreover if there is a valid causal basis to the relationship it may be claimed that a spatial model of the environmental pattern has been developed. In seeking a basis for such a model in contemporary research, the 'subregional wastes-pollution model' proposed by WOOD et al (1974) and described here in Chapter 13, contains the most explicit approach yet conducted in the UK. A two-stage process is envisaged, whereby (a) environmental conditions in an area are principally determined by the level of waste production within the area; and (b) "the generation of wastes within an area is determined by the degree and type of land use activity to be found there" (WOOD et al 1974, emphasis added). In spatial terms, Wood et al therefore see 'the degree and type of land use activity' as the fundamental environmental differentiator parameters[1]; other research, examples of which are described below, has attempted the classification of areas on much the same basis, commonly using (either explicitly or implicitly) two differentiator parameters which may generally be termed 'predominant land use' and 'distance from the city centre' (the latter being effectively an indicator of the degree of activity). It will be seen in section 4.3 that the TAE classification adopted in the research uses essentially the same parameters.

In the field of ambient noise, a simple classification of areas using

1. The assumption of 'functional zone independence' is crucial to the validity of this model.

both parameters is provided by the method given in BS4142 (BRITISH STANDARDS INSTITUTE 1967, 1975, and used also by other workers, for example ATTENBOROUGH et al 1976, GILFORD and NORRIS 1973). Residential and industrial land uses are differentiated and a distinction is made between urban and suburban areas (an implicit use of the 'distance from the city centre' parameter). The Tokyo ambient noise survey (TOKYO METROPOLITAN GOVERNMENT 1976) uses a more detailed classification although along similar lines to BS4142 (Appendix B.1 lists these and other classifications).

Within the field of sulphur dioxide air pollution a less qualitative approach is found in respect of the classification of areas, with a tendency for the more sophisticated studies to use quantified data on the pollution emission rates of area zones (for example BUSSE and ZIMMERMAN 1973, BALL 1976, 1978a); however this is sometimes reduced to qualitative urban fabric parameters reflecting housing density or population density (BENARIE 1976). A qualitative system of classification has been devised for the UK by the Warren Spring Laboratory (DEPARTMENT OF INDUSTRY 1975). This system, detailed in Appendix C.2, again makes an explicit differentiation by land use and implicitly also involves the 'distance from the city centre' parameter.However its accuracy as a method for the spatial classification of air pollution conditions has been questioned by its authors (WILLIAMS 1978), mainly on the grounds of poor attention to a 'functionally independent' zone size.

Since area appearance is a concept developed specifically for this study there is a limited amount of analogous research in the literature. The most relevant is the Buchanan classification of residential area quality (VOORHEES and ASSOCIATES 1971); the method is developed explicitly for the residential landuse type, but the 'distance from the city centre' parameter is very evidently implicit in the classification (see the detailed discussion in Chapter 7).

A principal aim of the research was to develop a single classification system responsive to the current methods for differentiating the conditions of each attribute, thereby achieving a unified approach. Section 4.3 discusses how this was achieved; it should also be noted that the concept of a unified approach is in principle considerably facilitated by the research's subsequent discovery that the attributes are significantly covariant over space (see Chapter 8.2).

4.2.3 Choice of TAE Zone Size

The land use typology in classification systems often involves mixes of land uses, and the extent and nature of this 'mixing' element in the classification, and therefore the identity of certain zone types, is dependent upon the size of zone whose urban fabric is categorised. For example, at the microscale limit of the building unit, very little mixing of activities would be observed; at the macroscale limit of the city itself, a mix of all activities would be virtually certain[1]. The choice of zone size therefore constrains the possible types of zone that may be defined, and consequently it is necessary to select the TAE zone size before a classification of zone types can be achieved.

The problem of zone size has already been investigated in 3.4.3 and in 3.5.1 the issue was extended to the TAE concept. The central issues were seen to be the theoretical requirement for 'functional zone independence', Batty's display-oriented objective of zone size minimisation, operational considerations about the appropriate resolution level, and the question of data availability. In this research it has already been mentioned that no specific policy context was available and so the operational context was necessarily restricted to the treatment of a particular case study area

1. To an extent of course this issue is also connected with the degree of homogeneity in zone conditions.

(the West Midlands Metropolitan County) and in association with this, the availability of data for such an area. For the research therefore, the selection of an appropriate zone size proceeded by (a) identifying the minimum zone size that would maintain functional zone independence; (b) modifying this size in respect of data availability and very limited operational considerations.

The paucity of the evidence from contemporary research allows no more than an approximate estimate of optimal zone size to be made in respect of the theoretical issues covered by (a) above, and to an extent the empirical research itself made further investigation in this area, especially in the case of sulphur dioxide (see Chapter 6.4). From the field of ambient noise, no indication of zone size whatsoever is given in the BS4142 method; in a study of New York, SENKO and KIRSHNAN (1971) use a 1 sq.mile zone as what SAFEER (1973) terms an "homogeneous sampling unit", while the Tokyo noise survey uses units of 0.5Km X 0.5Km. From the attenuation profiles given in DELANEY (1972), it would appear that the latter size is the likely lower limit that maintains functional zone independence. The Warren Spring Laboratory method for classifying areas with respect to their sulphur dioxide conditions also does not specify a zone size, but category 02 (see the full classification in Appendix C.2) implies that a zone radius of ¼ mile is appropriate. The study by MARSH and FOSTER (1967) in Reading used a variety of zone sizes and concluded that an optimal zone size would involve a radius of 1-2Km. In the method of SHARMA (1975) however a 1Km grid is used and on the evidence of this and the study by TURNER (1973) it would appear that 1 sq. Km. is the lower limit. Area appearance does not present diffusive problems and the issue of theoretical optimum zone size is more a question of defining the appropriate area over which visual appearance is to be assessed in order to preserve internal consistency (i.e. the extent to which 'views' are included). The Buchanan method treats census Enumeration Districts which on average appear to be smaller than 0.5 Km X 0.5 Km, and although the study of 'landscape attractiveness' used by SOUTH YORKSHIRE COUNTY COUNCIL (1978b) adopts 1 sq. Km. zones it is intentionally more responsive to 'views' than is necessary for an urban context, and so an optimal zone size would appear to be around 0.5 Km X 0.5 Km.

On the basis of this rather scanty evidence which only allows a cursory treatment of the theoretical issues, it was concluded that the minimum zone size for a unified TAE zoning system would be 1 sq. Km; this is also in line with the common unit used in other general environmental studies (for example SOUTH YORKSHIRE COUNTY COUNCIL 1978a, 1978b, CHESHIRE COUNTY COUNCIL 1977). Considering the issues under point (b) above however, it was found that while land use data was available to allow this size of unit to be examined, the data for the second parameter was more problematical. The choice and definition of this parameter ('road network density') is discussed in the following section, where it will be seen that the minimum area over which it could be accurately assessed was 1.25 X 1.25 Km. Consequently for this essentially pragmatic reason it was necessary to raise the selected TAE zone size to the 1.25 X 1.25 Km level. As mentioned, the lack of an operational context prevented an analysis of most of the operational requirements concerning resolution levels, and it was simply noted that the 1.25 X 1.25 Km unit would require a total of some 575 individual TAE zones in order to cover the WMMC. It was considered that this was a manageable number giving a display of pattern simple enough for an immediate overall visual impact, yet detailed enough to allow the trends and patterns associated with quite local features such as parkland and small towns (see the maps in Appendix A). At this very limited and qualitative level there was found to be no apparent operational reason for modifying the selection of the 1.25 Km X 1.25 Km TAE zone size.

4.3 THE CLASSIFICATORY PARAMETERS: HYPOTHESES, TYPOLOGY, AND THE RESULTING TAE TYPES

4.3.0 Outline

The research adopted 'land use type' and 'road network density' as the specific differentiator parameters evolving from Wood's general proposition of the 'degree and type of land use activity'. A systematic approach was taken in the derivation of the parameters and their typologies as described below; the resulting categories are treated independently in a matrix which thus defines the set of TAE types which it is hypothesised will differentiate the environmental pattern; these TAE types therefore provide the sampling frame for the empirical validation exercise described in the subsequent chapters.

4.3.1 Categorisation of the Land Use Parameter

Land use is a ubiquitous parameter in attempts to classify areas, and comprehensive land use data is in most contexts readily available to local authority departments. This is an important point since it has been established that a principal feature of the TAE mapping methodology is its capacity to give a spatially comprehensive prediction of environmental pattern, given a simple, readily available spatially comprehensive input of urban fabric data. In the case study area (see Appendix A) it was found that land use data could be obtained for most of the WMMC from secondary sources (past Structure Plan Reports of Survey) but the typologies of these sources, given in Table 4.1, and the zoning of the area-based measurements (on a 0.1 Km X 0.1 Km grid) require modification if a typology of land use is to be developed which may act specifically as an environmental differentiator at the scale of the TAE zone.

The moulding of the raw data into a form suitable as base data for the TAE methodology proceeded through two stages; (i) a reformulation of the raw typology into a set of fundamental land use activity types; (ii) a spatial aggregation of data into TAE zones in association with a TAE typology consisting of the fundamental activity types and their combinations or 'mixes'.

The typology of the raw data is designed to suit many purposes, and in order to reformulate it into a system for classifying environmentally distinct areas yet without redundant categories, it is necessary to aggregate some categories and subdivide others. The hypotheses for this process derive essentially from the functional relationship between land use activities and the environment. Two functionally distinct types of area are evident: (i) those areas which are <u>generators</u> of pollution and a poor environment (categories 0 to 4 in Table 4.1), and (ii) those areas which on the whole act as <u>attenuators</u>, due both to a lack of generator sources and the natural dispersion or decrease in intensity of effect with distance from the source (categories 5 and 6 in Table 4.1).

Category Name	Code
Residential	0
Industrial	1
Shopping	2
Business	3
Public Buildings	4
Public Open Space	5
Countryside	6

<u>Table 4.1</u> <u>Categories of Land Use Presented in 'Structure Plan Reports of Survey' Data</u>

Within the generator class, three environmentally distinct types of land use activity are found:

(a) <u>Residential</u> activities generate private transport noise, domestic activity noise due to such factors as children, lawnmowers etc., and evening domestic air pollution, while some (usually inner-city) areas have poor area appearance;

(b) <u>Industrial</u> activities are associated with heavy vehicle transport noise, industrial noise, air pollution (particularly from low level and ventilation emissions and predominantly in the daytime), and such areas commonly exhibit poor area appearance;

(c) Commercial activities show a high intensity and density of land use, with private, commercial, public transport and heavy vehicle noise, and prominent sulphur dioxide emissions from large-scale space-heating operations.

The basis for this classification derives from the evidence of contemporary research, details of which are given in Chapters 5,6 and 7, and in Appendices B and C. A similar consideration of the functional nature of the attenuator class resulted in the conclusion that only a single category existed, that of (d) open space. Deferring for the moment the fact that these land use activity types commonly exist in combinations and mixes within TAE-sized zones, it is evidently necessary to translate the raw data typology into the environmentally-derived land use activity types. Table 4.2 presents the 'conversion system' used in the research; it is seen that this is a typological aggregation process with the exception of the original 'public buildings' category. The activity characteristics of this land use type are split between those with an affinity to the commercial category (for example museums, city-centre public authority buildings,

Raw Data Category Title	Function	'Fundamental Activity' Title	Code
Residential Public buildings (suburban)	Generator "	Residential	0
Industrial	Generator	Industrial	1
Shopping Business Public buildings (inner city)	Generator " "	Commercial	2
Public Open Space Countryside	Attenuator "	Open space	3

Table 4.2 Reclassification of Raw Data Land Use Types into Fundamental Activity Types

libraries, hospitals and prisons) and those with an affinity towards the residential category (for example schools, suburban hospitals and residential homes). As a general rule it is possible to make the distinction on the basis of an inner city/suburban dichotomy, and in applying the Table 4.2

'conversion system' to the mapped data (see Appendix A) this somewhat arbitrary method was used.

The resulting 'fundamental' land use activity data is however still expressed in zones much smaller than the TAE, and the diversity of urban activity over space makes possible a considerable mixing of activities within TAE zones. Thus while some zones will be dominated by a particular 'fundamental' type many more will contain combinations, and to achieve a typology of the land use parameter requires that such mixes must be explicitly classified. Again considering land use functionally, three forms of land use activity mix may be identified;

(a) interspersion of generator and attenuator activities, where one dominates but is interspersed with smaller areas or 'pockets' of the other; for example the 'residential/open space mix' that occurs where suburban residential areas are frequently found in combination with small patches of green space and large gardens;

(b) 'bordering' between generator and attenuator activities, where a boundary exists between two substantial[1] areas of fundamental types; here dispersion of noise and, to a greater spatial extent, air pollution causes an increase of pollution in the attenuator and a decrease in the generator;

(c) bordering and/or interspersion between generator activities alone; this occurrence often leads to a qualitatively different environment, for example in the 'residential/industrial mix' which is most prevalent in the older urban areas and is therefore associated with a particularly poor environment, often poorer than is the case in either purely residential or purely industrial areas.

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1. Areas for example greater than 500m in diameter.

Although it is thus clear that mixes may occur in these three distinct forms, it was decided not to make an explicit distinction between types of mix purely on the basis of the form of the mix, firstly because this would have considerably increased the number of categories in the classification without any evidence that the representative environmental conditions of a zone will be distinctly different purely on account of the way in which mixing occurs, and secondly because zones of the TAE size may contain several instances of each form of mix. Consequently, mix types were identified purely on the basis of the land use activity components within the zone. In the absence of any guidelines in the literature it was decided to use a systematic bi-modal classification of mixes since this was the simplest method and was likely to encompass all the most prominent types of mix in zones the size of the TAE unit. Further research, had this been possible, might have identified certain tri-modal mixes (for example 'residential/industrial/commercial') which might be more distinctive than those bi-modal mixes defined systematically, but such study was beyond the scope of the research. Consequently the six possible bi-modal mixes were added to the four fundamental activity types to give a ten-category classification of land use as shown in Table 4.3. The precise criteria for applying the typology to

Code	Land Use Title	Function
0	Residential	Generator (pure)
1	Industrial	"
2	Commercial	"
3	Open Space	Attenuator (pure)
4	Residential/Industrial	Generator/Generator (mix)
5	Residential/Commercial	"
6	Industrial/Commercial	"
7	Residential/Open Space	Generator/Attenuator (mix)
8	Industrial/Open Space	"
9	Commercial/Open Space	"

Table 4.3 Classification of the Land Use Parameter by Land Use Activity Type

classify the proportional land use composition of the individual zones is described in Appendix A.

The classification given in Table 4.3 thus provides a typology of land use derived from a systematic analysis using hypotheses to identify environmentally distinct areas.

4.3.2 Derivation and Categorisation of the 'Road Network Density' Parameter

The use of the conventional 'distance from the city centre' parameter is not appropriate in the context of a large conurbation such as the WMMC. This is because conurbations have for the most part resulted from the conglomeration of many small industrial and commercial centres, interspersed with housing (in the case of the WMMC this is particularly true of the 'Black Country'). Consequently a dominant, free-standing city-centre structure such as that preassumed in the conventional parameter is not evident in the WMMC, except possibly in the case of Coventry and certain parts of Birmingham. In any case the 'distance' parameter is arbitrarily and inexplicitly defined, being commonly expressed through qualitative terms such as 'urban', 'suburban', 'rural', etc. Thus it was necessary to examine the theoretical factors more rigorously in this research in order to develop a more useful and precise parameter.

A second 'differentiator' parameter in environmental area classification is made necessary by the fact that environmental conditions vary significantly within categories of area defined simply by land use. This is because environmental conditions are affected by factors other than land use type as such, and the task of the further parameter in classification systems is to reflect the influence of these other factors, in causal terms if possible. The argument put by WOOD et al (1974) and others is that it is essentially the "degree" or intensity of land use that causes conditions to vary between areas with otherwise similar land use type. Assuming this to be true, the 'distance' parameter is evidently effective only in as much as it is an indicator of land use intensity. A detailed study of Birmingham (JURUE 1977a) has shown that the relationship between land use intensity and 'distance from the city centre' is indeed valid for many types of land use. An example is given in Fig. 4.1, where it is seen that the empirically-derived relationship has a similar form to the negative exponential relationships that are known to exist between population density and 'distance from the city centre' (e.g. MILLS 1970). Thus it is reasonable to conclude that the commonly-applied 'distance' parameter is effectively a surrogate for Wood's theoretically-derived 'degree' of land use.

The main theoretical factors governing the relationship between environmental conditions and land use intensity may be illustrated by examining the 'residential' land use category where the most notable within-category variations in noise, sulphur dioxide, and particularly in area appearance, are found as can be seen from the classification systems discussed earlier. The chief reasons for the variations are as follows: with ambient noise, the background effects of traffic (which is the most prominent source of urban noise - see Chapter 5.5) are higher in the densely-trafficked inner urban areas than in the more sparsely-laid-out suburbs; sulphur dioxide is clearly emitted in greater quantity per unit area from dense inner-city housing areas as compared with the less dense outer suburbs, this effect being compounded with correlated socio-economic differences and smoke control policy; and area appearance is, as the Buchanan classification shows explicitly, highly correlated with the age as well as density of the built environment, with the peripheral growth pattern of cities leading to the oldest and least attractive areas being located in the urban core. The above effects are particularly noticeable in the residential category (chiefly because it is the most pervasive) but are equally applicable, if less strongly and evidently so, in the industrial and commercial categories and the mixes.

Fig. 4.1. Variation in 'Proportion of Land Surface Covered by Permanent Buildings' with Distance from the City Centre

(Source: JURUE 1977a)

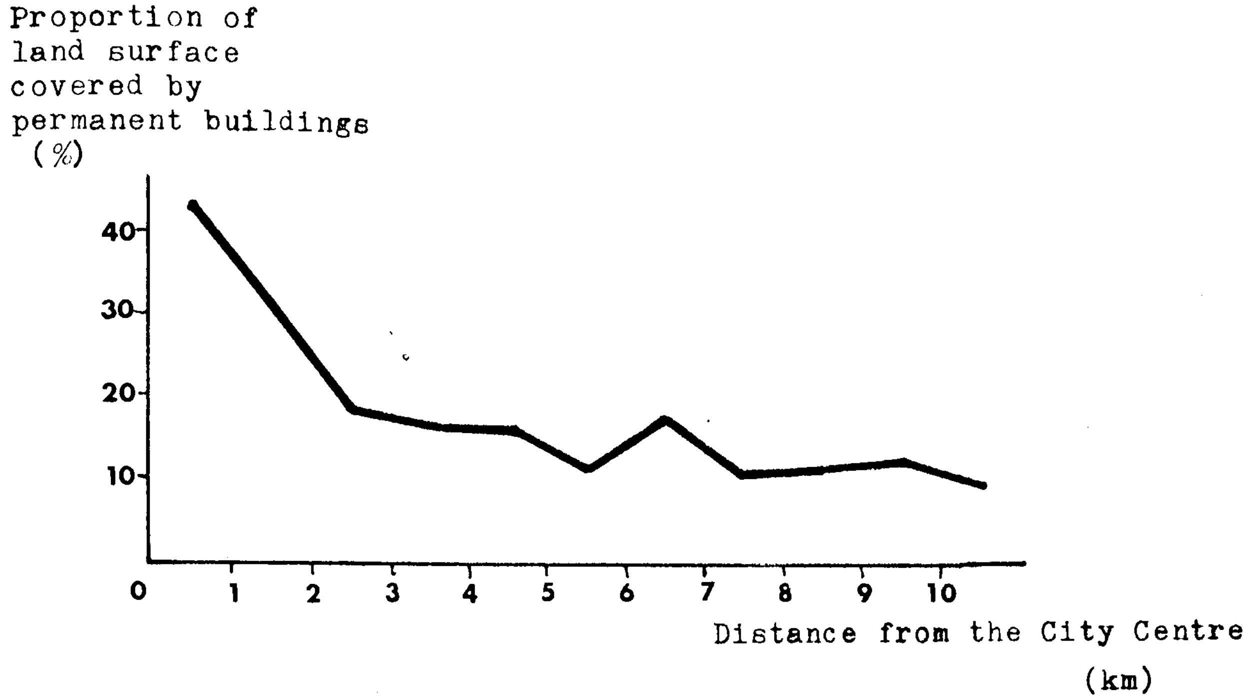
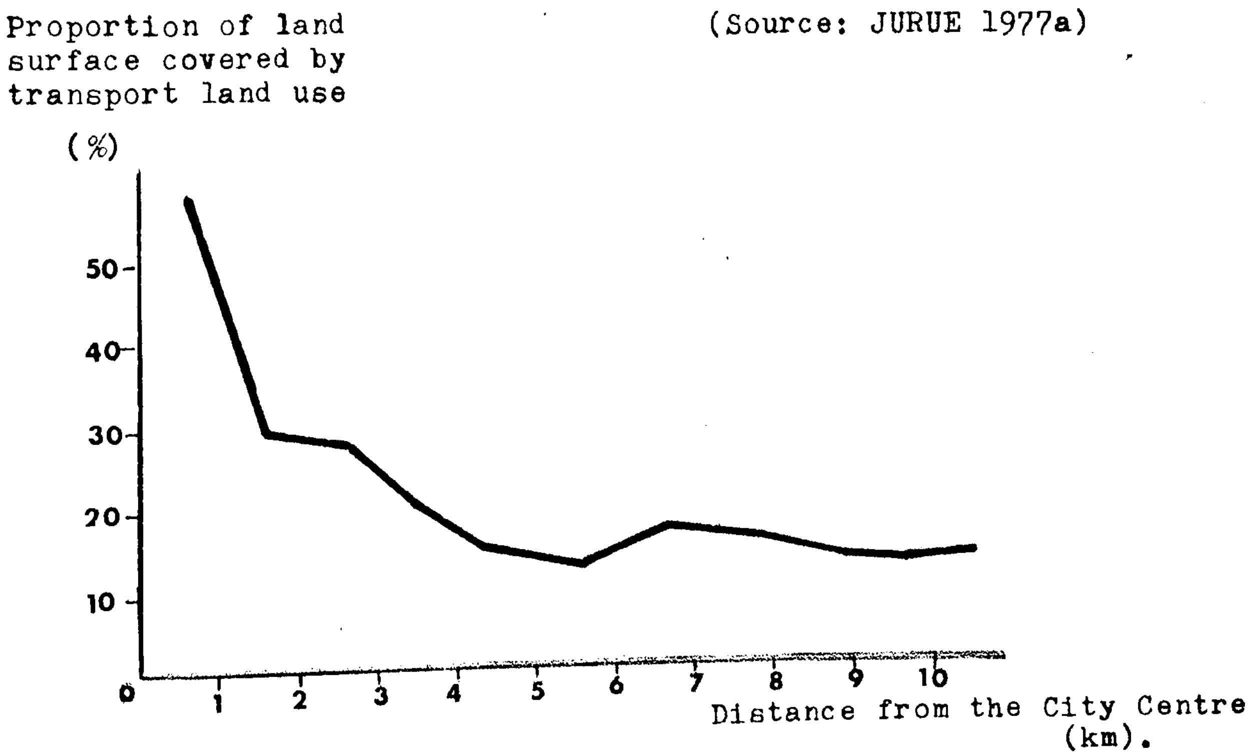


Fig. 4.2. Variation in 'Proportion of Land Surface Covered by Transport Land Use' with Distance from the City Centre

(Source: JURUE 1977a)



It has already been stated that the parameter 'road network density' was chosen to represent the effects of the above factors. The choice of this parameter was founded on three basic hypotheses, described below; it should be noted that JURUE (1977a) provide empirical evidence that 'road network density' is related to 'distance from the city centre' (as illustrated in Fig. 4.2), and therefore to land use intensity.

(i) Background traffic noise is hypothesised to be causally related to an area's local traffic density. The traffic density is in turn assumed to be proportional to the density of the local road network. Thus 'road network density' acts as a 'predictor' parameter of the background traffic noise (a similar approach has also been used by SOUTH YORKSHIRE COUNTY COUNCIL (1978b)).

(ii) Sulphur dioxide air pollution is known to be correlated to the parameters 'population density' (BENARIE 1976) and 'housing density' (MARSH and FOSTER 1967), and therefore to the general land use intensity parameter. As stated above, there is empirical evidence to support the hypothesis that 'road network density' is correlated with landuse intensity, and therefore with sulphur dioxide air pollution.

(iii) Area appearance has already been described as being associated with land use intensity and distance from the city centre. The above indicates that there is evidence to support the hypothesis that it is therefore related to the 'road network density' parameter.

The Appendix A describes the simple, readily available method that was used to obtain and classify data describing the 'road network density' parameter, resulting in a typology of zones consisting of three categories labelled 'dense' (A), 'medium' (B), and 'sparse' (C).

4.3.3 The Definition of TAE Types

Treated independently the typologies of the two differentiator parameters form a two-dimensional matrix for classifying the TAE zones into 'TAE types', given by the 'cells' in this matrix. Each TAE type is therefore a category of area whose environmental conditions are, through the hypotheses discussed in the foregoing, assumed to be distinctly different from those of the other TAE types. Together therefore the categories constitute a typology of the TAE concept, a method for classifying areas, by hypothesis, into types of environmental conditions on the basis of a classification of the urban fabric. Table 4.4 shows the TAE type matrix, and within the appropriate cells are entered the numbers of zones and the proportion of the WMMC area which, using the mapped data as discussed in Appendix A, were found to lie within that given category. Some categories were found to contain an insignificant number of zones - indeed some potential TAE types, for example 'open space, dense network' and 'commercial, sparse network' are for theoretical reasons highly unlikely to occur at all. This reveals the fact that although the two parameters have been treated in the foregoing as independent, there is in reality a certain functional relationship between them (for example, commercial activities cannot function in areas with 'sparse' road networks). All categories containing less than 0.5% of the WMMC area were discounted in the final definition of the TAE typology, which therefore contained the nineteen TAE types identified in Table 4.4.

4.4 EXPERIMENTAL DESIGN FOR TESTING THE HYPOTHESES

4.4.0 Outline

The principles of the empirical techniques used to test the TAE mapping methodology are summarised below, and the case study context is described.

4.4.1 Principles of the Empirical Research Case Study Method

If based upon sound hypotheses, the TAE types should encompass the full range of urban environmental conditions, and methodologically therefore

Land Use Categories	Network Density Categories			Land Use Proportions
	A	B	C	
0	35(6.1)	51(8.9)	13(2.3)	99(17.3)
1	6(1.1)	12(2.1)	-	18(3.2)
2	10(1.8)	-	-	10(1.8)
3	-	-	131(23.0)	131(23.0)
4	20(3.5)	51(9.9)	*	71(12.4)
5	7(1.2)	11(1.9)	4(0.8)	22(3.9)
6	3(0.6)	9(1.6)	*	12(2.2)
7	16(2.8)	115(20.2)	50(8.8)	181(31.8)
8	-	9(1.6)	17(3.0)	26(4.6)
9	-	*	-	-
Network density proportions	97(17.0)	258(45.1)	215(37.9)	570(100.0)

Key

- : No TAEs found within the category

* : Less than 0.5% of WMMC area found to be within the category

Table 4.4 TAE Type Matrix, giving the Number and (Percentage) of TAEs in the WMMC Falling into each TAE Type the TAE typology lays out a sample frame for the examination of the spatial variation of environmental conditions. Furthermore, when the TAE typology is expressed cartographically in a classified set of choropleth grid zones (Appendix A describes how this was achieved for the WMMC), the spatial data provides both a cartographic sampling base map (for location of appropriate sample zones), and also the fundamental underlying base map for the predictive mapping exercise (since it represents the classified urban fabric pattern, onto which an environmental 'relief' is projected through the calibrated relationship).

Returning to the principles of the TAE mapping methodology as described in Chapter 3, it is evident that the empirical case studies, which were set up as the means for testing the TAE methodology in the WMMC for the selected case study attributes, have three principal objectives:

(i) to validate the hypothesis that a statistically significant relationship exists between the environmental conditions of TAE zones and their TAE type;

(ii) to calibrate the relationship by allocating a 'typical' environmental condition to each TAE type defined in the TAE type matrix (Table 4.4);

(iii) to group TAE types into five categories with similar environmental conditions, and to map the spatial distribution of the five groups within the WMMC through the 'area-based prediction' method.

These key objectives are recapitulated at the beginning of each case study Chapter and the methods through which they were pursued empirically for the given environmental attribute are described. While methodological differences between the studies exist, mainly due to differences in the methods of data collection and the scale properties of the data, the essence of the approach is in each case the same. The hypothesis is tested by firstly obtaining data on the environmental conditions within the TAE types, and secondly performing a statistical analysis to test whether the between-

TAE type differences are statistically significant.[1] A statistically significant difference was taken to indicate that the hypothesis was valid. This being so the 'typical' (mean or median) environmental conditions of each TAE type are obtained directly from the relevant measurement data, noting that within-type variance in the data reflects the accuracy of the resulting 'TAE prediction model'. Through the grouping procedure outlined in section 3.4.1 and detailed in the relevant chapters the TAE prediction model is then re-expressed in terms of five categories of the range of observed environmental conditions. Thus given an 'input' base map consisting of TAE types, it is possible to achieve by direct conversion an 'output' map showing the environmental pattern consisting of the five environmental categories.

4.4.2 The Case Study Context

It has already been established that the WMMC was used as the empirical case study area; a detailed physical description of the area is given in Appendix A.3. The research was able to utilise information and resources for the empirical study through participation in an investigation of the 'background' noise conditions prevailing within the WMMC. This exercise was undertaken as part of an overall policy context involving the collection of data for the WMCC Structure Plan Report of Survey, and the contribution of the research to the noise context of this study is published elsewhere (WILLIAMS and POCOCK 1977, JURUE 1977b, WEST MIDLANDS COUNTY COUNCIL 1978). Essentially the purpose of the exercise was to provide a map of ambient noise conditions which would then be used in an evaluative context, putting into perspective the noise impacts[2] of various strategic transport options. This is a somewhat limited example of the 'base map' application in Environmental Impact Analysis, discussed in Chapter 1.1. While it was not

1. Note that this statistical test is effectively that used in the 'natural zoning' approach except that the zone configuration is predetermined by the TAE grid system.

2. determined in other research (JURUE 1977b).

considered worthwhile to use this limited study as a specific operational policy context case study for the research, it is nevertheless pertinent to note that the TAE mapping methodology can make a useful contribution to such applications.

Under the auspices of this context a field survey was undertaken, the relevant aspects here being the sampling of ambient noise and area appearance conditions. The methods of measurement for these attributes are discussed in Chapters 5 and 7 respectively, and the experimental field survey design is described in Appendix A together with the survey technique. The investigation of sulphur dioxide conditions was forced to rely on secondary data sources (the National Survey data) for reasons described in Chapter 6. In each case the intention was to characterise the 'typical' conditions of the set of sample TAE types, and to perform the tests described in section 4.4.1; the field survey used TAE types directly as a sample frame, while the sulphur dioxide study required the development of a diffusion model before the TAE method could be tested.

4.4.3 Conclusions

This Chapter has laid out the explicit hypotheses which are encapsulated in the TAE typology. From this it was possible to specify precisely the experimental design for testing the TAE mapping methodology; for each case study attribute the three key objectives were to validate the hypothesised role of the TAE, calibrate the resulting 'area-based spatial prediction model', and apply it as a mapping methodology. The main factors determining the form and content of the case study approach were seen to be; the criteria for the selection of ambient noise, sulphur dioxide air pollution and area appearance as representative ambient attributes, the choice of a 1.25 X 1.25 Km TAE zone size, and the use of the WMMC as a case study area with urban fabric data obtained from readily available sources. The thesis now proceeds to the four technical chapters which discuss in detail the testing of the TAE mapping methodology for the three environmental attributes and the further 'aggregate environmental conditions' indicator.

CHAPTER 5

CASE STUDY OF URBAN AMBIENT NOISE

5.0 INTRODUCTION

The purpose of this chapter is to present and discuss an account of the empirical case study of urban ambient noise conditions[1] in the WMMC in which the TAE mapping methodology was tested. The aims, objectives, hypotheses and tests which comprised the empirical research method are outlined in this introduction, together with a synopsis of the remainder of the chapter.

5.0.1. Empirical Research Method

(a) Aims

The principal aim of the case study was to test the application of the TAE mapping methodology to urban ambient noise conditions in the West Midlands Metropolitan County. Since the test was undertaken using primary data it was also necessary to develop a method for the field survey, and analysis and interpretation of the data. The general problem issues in measuring, predicting and mapping ambient noise were examined, together with the methods of other workers, in order to provide a basis of contemporary knowledge upon which this research would be developed and assessed.

(b) Objectives

In accordance with the principles of the TAE mapping methodology established in the foregoing chapters (see especially section 4.4.1), the empirical case study has three main objectives:

(i) to test the hypothesised environment/TAE type relationship in the case of ambient noise;

(ii) to calibrate the TAE prediction model by associating each TAE type

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1. Other workers, for example SAFEER (1973), have described ambient-noise as 'community noise'.

with a 'typical' ambient noise condition;

(iii) to apply the model as a mapping method, taking urban fabric 'input' data for the WMMC expressed in terms of TAEs and expressing the model 'output' predictions in terms of five classes of noise condition obtained by grouping the TAE types.

Empirically therefore the chief concern was to obtain ambient noise data to allow these objectives to be pursued. A field survey was used to obtain noise measurements at randomly selected sites within TAE zones sampled from each TAE type. A simple short-period manual sampling technique was used to derive indices equivalent to the percentile indices L_{10} and L_{90}, from which the L_{eq} could be estimated.

(c) Hypotheses

Chapters 3 and 4 indicated that the TAE methodology was based on the key hypothesis which, in the case of ambient noise, holds that the variation in the ambient noise conditions of the zones over the study area is significantly associated with the variation in the TAE type of the zones. The empirical study in fact examined the equivalent 'null hypothesis', that no statistically significant difference existed between the noise levels of the various TAE types.

(d) Tests

The null hypothesis was tested statistically using the standard 'analysis of variance' F-test, upon data consisting of the noise levels measured within sample TAEs of each type. In order to ensure that the data allowed a valid test of the hypothesis, a detailed analysis of the spatial and temporal errors of estimate in the sample data was found to be necessary and certain corrections to the F-ratio were made. The investigation of sampling errors also allowed the accuracy of the TAE prediction model to be determined. As a result of the investigation certain additional contributions to the theoretical knowledge of urban ambient noise climates were made; principally these concerned the development of an empirical model for predicting the general increase in ambient noise levels caused by windspeed (from which it was possible to normalise all observed noise levels to a standard 'light wind' conditions), and enhanced knowledge of the spatial and temporal variability of noise levels in different types of area.

5.0.2 Synopsis of the Chapter

The next section provides a general review of the problem of measuring and predicting urban ambient noise conditions, in order to introduce the nature of the methodological problems encountered in the case study. Section 5.2 describes the validation of the TAE hypothesis using the data obtained in the field survey, and the subsequent calibration of the TAE prediction model. The following section describes the empirical techniques for deriving and achieving the inidicator measurements through a survey method and for analysing the sample data to obtain the errors of estimate which are associated with the data used in the testing and calibration stages. The additional contributions to theoretical knowledge arising from the survey and analysis of ambient noise conditions are discussed in section 5.4. Section 5.5 approaches the final objective concerning the application of the prediction model as a mapping method, describing the method of grouping the TAE types into five classes of noise condition and discussing the most prominent sources of noise within each class in connection with its urban fabric characteristics, before presenting maps of the noise conditions over the WMMC. The chapter concludes with a comparison between the results of this research and those of other contemporary studies, and a general summary of the case study and conclusions on the performance of the TAE mapping methodology. Technical matters associated with this chapter are presented in Appendix B.

5.1 THE BASIC PROBLEMS IN THE MEASUREMENT AND REPRESENTATION OF URBAN AMBIENT NOISE CONDITIONS

Most of the basic problems in obtaining a spatially comprehensive data set for mapping purposes have been discussed in general terms in Chapter 3 (sections 3.1 and 3.2). This section describes the issues in detail as they are encountered in the specific context of ambient noise studies. In this way a basis of contemporary knowledge and procedure is established against which the performance of the TAE mapping methodology can be compared and assessed. In addition the empirical problems, mainly those concerned with measurement, sampling and representation, are described, thus providing an introduction to the issues confronting the field study sampling approach that was used as the means for obtaining the data upon which to test the TAE mapping methodology.

It will be seen that urban ambient noise is an example of an environmental attribute that exhibits a particularly high degree of spatial and temporal variability. The problems that these characteristics pose in environmental mapping have already been summarised and the ambient noise case study provides a practical context in which to pursue the issues in greater depth. The substance of the problem lies essentially in the obtaining of a spatial data set for mapping purposes, and is well summarised by SAFEER (1973): "a single noise level value or number for a given moment in time at some fixed point in the community is not a measure of the noise level in that community. In many cases it is not even a measure of the noise level at that particular point. The single noise level number is a statistic, subject to variation, which may or may not, depending upon the degree of variation, be a good representation of the noise level at the measurement site. Similarly, depending upon the variation among sites, the single number for a single site may or may not be representative of the noise levels for a much larger area. Finally, even if the single number at a single point represents a representative noise level for some given point in time, it may or may not be representative of some longer time period." It will be seen that the TAE mapping methodology, incorporating the empirical testing and calibration procedures described in this chapter, enabled these problem issues to be overcome.

5.1.1 Methods for Assessing the Spatial Pattern of the Urban Ambient Noise Environment

Chapter 3.1.5 has shown that the spatial data set upon which all mapping methods rely may be derived either by measurement, through an observation of a spatially regular, comprehensive set of sample sites, or by prediction, through calibrated point-receptor[1] or area-based[2] models. Studies of urban ambient noise have incorporated examples of all these types of method, as described and assessed below.

The measurement-based methods are the least common because of the practical difficulties in obtaining sufficient data and interpreting the spatial pattern. These difficulties result from the particularly high variability in noise conditions that occurs over a very small spatial scale (as stated in the climatological analogy given in Chapter 3.1, the equivalent of 'tropical' and 'arctic' conditions are encountered over distances of some few hundred metres). Thus if the pattern of noise conditions, or the mean noise level of a given area, are to be estimated accurately a high spatial sampling density of measurement sites is required.[3] Studies at the urban scale and larger are commonly unable to support the levels of survey resources necessary for the required sampling densities to be maintained over the whole study area. In the New York

1. Point-receptor models predict noise levels at receptor sites from given sources.

2. Area-based models predict 'typical' noise levels for given types of area.

3. For example, 25 sites per square mile have been recommended (SENKO and KIRSHNAN 1971), as discussed in Chapter 5.3.1.

noise survey (SENKO and KIRSHNAN 1971) the resources were available, and a choropleth 'approximation zone' grid (1 sq. mile) was mapped; in the West Midlands Noise Survey however (GILFORD and NORRIS 1973), a budget that was much more realistic to the operational context of this research was used, and the consequent sampling density was so low[1] that the resulting isoline map was virtually meaningless.

Both the point-receptor and the area-based predictive techniques rely in part or in full upon the use of deterministic theory, and in consequence the need for observation data is reduced to that, if any, necessary for calibrating the predictive relationship through which the theory is expressed. This is a considerable advantage where direct comprehensive measurement of the study area is infeasible at the sampling density necessary for meaningful results; calibration measurements may be made, as they were in this research, over small 'sample frame' areas where it is practicable to attain the required sampling densities. Even when the model prediction error is included it may be possible to produce comprehensive data for the study area more accurately than could be feasibly obtained through measurement alone.

The point-receptor techniques may or may not involve explicit propagation theories. The studies by SOUTH YORKSHIRE COUNTY COUNCIL (1978b) and CHESHIRE COUNTY COUNCIL (1977) do adopt propagation theories such as those developed by DELANEY et al (1971), notwithstanding the limitations of this appraoch in the urban (and specifically urban-scale) context as seen below. The problem of scale arises from the need for detailed knowledge of the type, strength and condition of local sources; in the Cheshire case the problem was mitigated by restricting the study to a part of one urban

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1. 1 site per 3Km X 3Km grid square zone.

area; the South Yorkshire Study was equivalent in scale to the county-wide context of this research, and encountered a considerable data collection and analysis problem and required approximations to the theories to be made. The theories themselves are of questionable validity in the urban scale context, as stated by PRABHU and CHAKRABORTY (1978), "much attention has been paid to the prediction of urban noise levels based on the knowledge of source characteristics and the propagation path. Such prediction methods, however, are restricted by the multiplicity of different types of sources in any urban area and by the limitations of sound propagation theories in complex urban situations". The particular complexity of urban noise patterns occurs because "the noise level at any point in the community is the resultant of a complex inter-action of a large number of independent noise sources under varying atmospheric, topographical and physical attributes of the area surround the measurement site" (SAFEER 1973). In general therefore the propagation-based point-receptor techniques are neither practicable nor valid in the context of large-scale urban ambient noise mapping exercises.

The point-receptor techniques which have avoided specific use of propagation theories are generally based on what is termed the 'binary (category) variable prediction model' (e.g. ATTENBOROUGH et al 1976, PRABHU and CHAKRABORTY 1978). A receptor site is identified by parameter categories describing both the type of area in which the receptor is situated (for example the general land use type of proximity to the city centre[1]), and the site-identity of the receptor (for example proximity to the nearest road, or type of noise predominating at the site).

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1. A detailed list of area-type parameters and categories is given in Appendix B, and was used in sections 4.2 and 4.3 in the development of the TAE hypotheses.

The model works by identifying a 'notional background' noise level, and adding further noise levels appropriate to the area and site-identity categories of any given receptor (under the assumption of no interaction between the area-type and site-identity parameters). It will be evident however that the replacement of specific propagation theories by 'site-identity' parameters is merely to substitute a more approximate and empirical expression to predict spatial variation. The problem in using this approach as a mapping method is that a very large amount of spatial data on the pattern of site identity is still required.

The area-based methods used in contemporary research are similar to the 'binary variable' model above except that the site-identity parameter is omitted and the prediction is of the 'typical', mean noise level for a given area-type rather than for a specific point in space (e.g. BRITISH STANDARD INSTITUTION 1967, PRICE 1972, TOKYO METROPOLITAN GOVERNMENT 1976). The TAE methodology tested in this case study is of this class of method, but with an explicitly spatial element involving the treatment of specified units of area (TAEs). This is in contrast to the above methods where the models result from the random (grid-based) measurement of noise over the study area, and the classification of measurements by their area-type without an explicit definition of the size and boundaries of the area to be considered. The pooling and averaging of all measurements in the same area-type results in a typical (mean) noise level for certain categories of area, but without the spatial expression and means for translating the model into a mapping method. The model may be described as an 'area-category prediction model', whereas the TAE methodology leads to an 'area-based spatial prediction model'.[1]

This broad appraisal of the methods used in contemporary ambient noise studies therefore leads to the following general conclusions:

(i) that the high spatial variability of ambient noise over short distances means that usefully accurate measurement-based methods are not feasible at the urban or County scale;

(ii) that the interactions of sound propagating from the multiplicity of sources in an urban area makes the use of point-receptor propagation-based techniques impracticable and invalid;

(iii) as a result, urban noise is an 'ambient' phenomen (as defined in Chapter 4.1) and can only be represented spatially by area-based data;

(iv) the contemporary area-based prediction methods have identified categories of area but have neglected the zone delineation problem - thus the predicted data cannot be represented cartographically;

(v) the TAE mapping methodology follows the approach of contemporary area-based prediction methods but includes a specifically spatial element thereby facilitating mapping; Appendix B also shows that

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1. The contrast is also evident in the fact that the TAE methodology takes measurement in a priori designated and classified zones, while the other models take spatially random measurements, and classify and designate (arbitrarily) the area zones a posteriori.

the TAE typology is much more extensive and comprehensive than other equivalent classifications.

Further comparisons particularly concerning the TAE prediction model performance, are given later (see section 5.6).

5.1.2 Ambient Noise Measurement and the Problem of Temporal Variation

Although the adoption of a predictive approach to determining the pattern of ambient noise conditions over the study area reduces the data collection exercise, it is still necessary in those studies where calibration data are required, to take a large sample of observation sites, owing to the high short-distance spatial variability. Constraints of available time and resources dictate that each site may only be observed for a comparatively short period. This leads to the second sampling problem, that of temporal sampling error, since urban ambient noise is also highly temporally variable.

The problem of temporal variation is approached through considering ambient noise as a statistical phenomenon (SAFEER, 1973, SCHOLES and SALVIDGE, 1973, SCHULZ, 1972, FISK, 1973). Two levels of analysis are made, firstly of variations within the sample period, and secondly of variations within a long-term or 'climatic' period. The variations in noise observed within the sample period are taken to exhibit a statistical distribution of noise levels which may be represented by statistical parameters. The most common statistical indicators are the percentiles L_{10}, L_{50} and L_{90}, and the 'energy equivalent' continuous sound level, L_{eq}.[1] Despite the increased popularity of L_{eq}, particularly within the EEC, most ambient noise surveys

1. Other noise indices have been developed, for example NNI, TNI, CNR, L_{NP}, but are either limited to particular kinds of noise (e.g. aircraft in the case of NNI), or are more complicated to derive than those mentioned in the text.

have adopted the percentile indicators L_{10} and/or L_{90} (MOCHIZUKI 1967, SENKO and KIRSHNAN 1971, PRICE 1972, SAFEER 1973, SCHOLES and SALVIDGE 1973, GILFORD and NORRIS 1973, ATTENBOROUGH et al 1976, PRABHU and CHAKRABORTY 1978). These indicators, generally representing the upper and lower levels of noise within the sample period, are simple to measure or estimate (an important consideration in ambient studies where a large sample of sites is required), and the value of L_{eq} may be estimated from them (see section 5.3.1). Consequently they were adopted in this research, and Section 5.3 describes in detail the method used in the empirical case study for estimating these two indicators using a simple hand-held sound level meter.

Because of the long-term variation in noise levels through the day and between different days, the parameters describing a sample distribution are only estimates of the parameters that would describe a long-term 'population' distribution of noise levels. Consequently a second stage of statistical analysis is necessary, applying to the statistical indicators themselves rather than instantaneous noise levels, in order to assess the accuracy of estimating the long-term or 'climatic' mean values of the indicators using sample data.

The general issues surrounding the choice of an appropriate 'climatic' period have already been addressed in Chapter 3.1.5. It was seen that the 'climatic' period constitutes the time interval over which the variation in conditions is assessed resulting in a statistical distribution or 'population' of conditions; this population may then be represented by a statistical parameter of the distribution (commonly the mean) which is then interpreted as a representative of the conditions obtaining over the 'climatic' period as a whole. It was also seen that where the population is estimated by sample data (rather than through continuous monitoring i.e. full enumeration) it is necessary that the samples be random, independent, and unbiased; thus a criterion for selecting an appropriate 'climatic' period is that the 'climatic' period should exclude trends and cycles. Since the temporal variation of ambient noise has a distinctly behavioural cause however, such trends and cycles do occur over time, the most notable being the diurnal and weekly cycles. These are discussed in detail in Appendix B, where it is seen that workers have generally distinguished three particular 'climatic' periods, normally labelled 'day', 'evening' and 'night'. The distinctiveness of these periods has led GILFORD and NORRIS (1973) to produce separate maps for these three 'climates'. The working week is also distinguished from the weekend period (ATTENBOROUGH et al 1976), and Appendix B shows the rationale behind the choice of the 'working weekday' (09.00 - 17.30, Monday to Friday) as the 'climatic' period to be studied in the research. It is over this period that the ambient noise conditions are at their most stable. This means that the 'climatic' population of noise levels has the smallest possible variance, and consequently the error in using any given sample value to represent its population mean is minimised.

A statistical analysis of sample data is required in order to estimate the variance of sample indicator values around their population mean. Once this is achieved the 'error of estimate' of any sample indicator measurement may be quantified, and therefore the accuracy of any use of the measurement as a representative indicator value may be determined. This, as already intimated in section 5.0 and made clearer in the following sections 5.2, is an essential prerequisite in testing the TAE hypothesis and establishing the accuracy of the prediction model. The techniques for assessing the sample errors of estimate, described in section 5.3, are complicated by a number of factors concerning the nature of the variance, and represent a considerable research effort.

This section has summarised the various methods through which contemporary research has approached the problem of assessing the ambient noise conditions of urban areas. The methodological problems common to all methods of mapping concern the high degree of spatial and temporal variability exhibited by urban ambient noise. Both practical and theoretical factors constrain the use of measurement-based and point-receptor prediction methods, and area-based methods have paid little attention to zone delineation and have instead involved only spatially aggregate 'category' predictions. Consequently, large-scale maps of urban ambient noise have rarely been achieved in contemporary studies without incurring exceptional survey costs. It has been shown that the TAE mapping methodology represents an advance upon the alternative methods because the measurement element is reduced to a calibration exercise which may be conducted over a limited number of sample areas where the necessary high sampling densities may therefore be achieved with only modest resources. The following section describes how the TAE hypothesis was tested and the spatial prediction model calibrated using a field survey and an analysis of data which overcame these problems.

5.2 THE TEST OF THE CENTRAL HYPOTHESIS, AND CALIBRATION OF THE TAE PREDICTION MODEL

5.2.0 Outline

This section describes the test of the central TAE hypothesis and the calibration of the TAE prediction model; these were stated in section 5.0 as being two of the three key objectives concerned with the testing of the TAE mapping methodology. To recapitulate, the TAE hypothesis holds that urban ambient noise levels are significantly associated with the TAE type of the zones in which they obtain. Put another way, it is hypothesised that the classification of noise levels according to the TAE type of the zone in which they are found explains a significant proposition of the total (spatial) variance of noise levels over the study area as a whole. A statistical test of this hypothesis is made through application of the 'analysis of variance' F-test to data consisting of noise levels sampled from zones of each TAE type. The TAE prediction model, the validity of which is dependent upon the validation of the hypothesis, is calibrated by allocating 'typical' noise levels to each TAE type, these consisting of the means of the indicator measurements observed within each type; the accuracy of the model is then assessed. Before describing the empirical results in relation to these objectives it is necessary to summarise the survey and data collection exercise in order that the empirical methods may then be detailed and the statistical problem issues more clearly understood.

5.2.1 Derivation of the Data for the Test and Calibration Exercises

The field survey involved the measurement of noise levels within sample TAE zones. Each TAE was surveyed over a single working day, and therefore all TAEs were surveyed on different days. Three survey phases were undertaken. In Phase 1, nineteen TAEs were surveyed, one for each of the types as defined in Chapter 4, selected at random from the study area. These nineteen TAEs constituted the basic sample frame for the collection of data upon which the hypothesis test and model calibration were performed. The location of these TAEs, together with other details of the survey, are given in Appendix A. Phase 2 centred upon a sample survey to test whether the Phase 1 zones were acceptably representative of the conditions within other zones of the same type. A final Phase 3 survey involved return visits to seven TAEs in order to investigate the long-term temporal variations in urban noise conditions.

In the surveying of each individual TAE, the chief issues were found to be, (a) the measurement technique and sampling time employed at each site, (b) the choice of spatial sampling density, (c) the location of sample sites, (d) the statistical treatment of the data to allow the empirical exercises to be undertaken; details of these issues are discussed in section 5.3. Briefly, the measurement technique involved the determination of what were termed the 'upper and lower noise levels' (UNL and LNL) applying to a total sample period of ten minutes at each site. Section

5.3.1 shows that on the evidence of this and other research, these simple measurements, derived from a hand-held sound level meter, may be taken as equivalent to the percentile indicators L_{10} and L_{90}, and it should also be noted that L_{eq} may be estimated from them.[1] The temporal sampling error of estimate for such short-period samples is discussed in section 5.3.2. Twenty sample sites were observed within each TAE, distributed through the zone in a random stratified sampling pattern as discussed in section 5.3.2 and Appendix A.

As stated, the results of Phase 1 were used in the hypothesis testing and model calibration exercises detailed in this section, while Phases 2 and 3 were analysed to provide further statistical knowledge of spatial and temporal variation without which the testing and calibration could not properly be conducted. This statistical analysis is described in section 5.3 and 5.4; the most significant result is seen to be the development of an empirical model for predicting the effect of wind on ambient noise levels. This enabled all observed noise levels to be normalised to a standard 'light wind' condition - a necessary requirement in a study where noise levels observed under different wind conditions have to be compared.

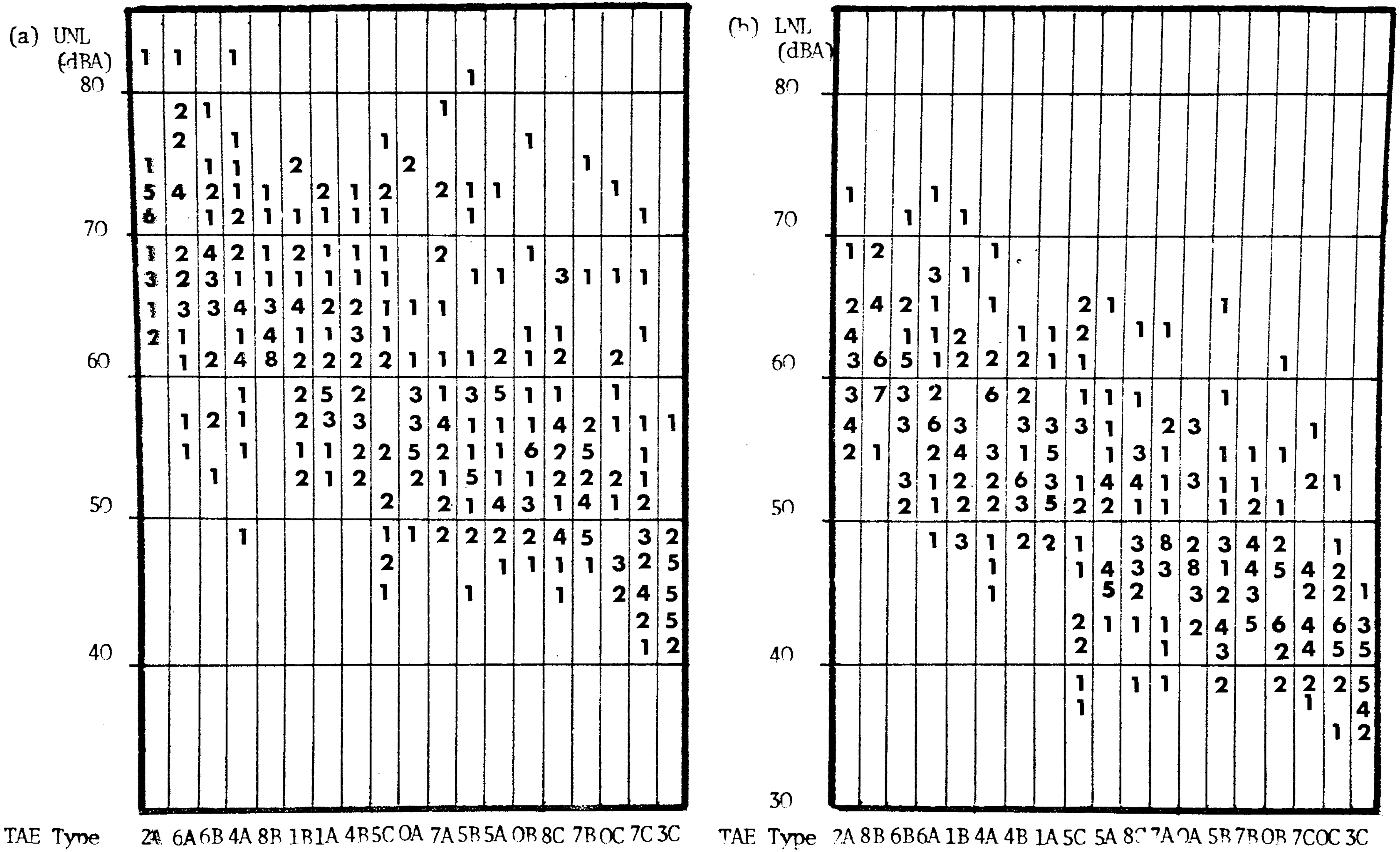
5.2.2 The Test of the TAE Hypothesis

The general TAE hypothesis states that urban ambient noise levels are significantly associated with the TAE type of the zone in which they are found. The statistical test however is necessarily applied to the corresponding null hypothesis, that samples of noise levels taken from different TAE types come from the same parent population.

The Phase 1 survey data upon which the test was performed are summarised in Figs. 5.1(a) and (b) for the indicators UNL and LNL respectively, a separate test being undertaken for each indicator. The figures show the nineteen TAE samples, each of a different type and each

1. Recent advances in instrumentation mean that the Leq may now be measured accurately with a hand-held meter simultaneously with the percentile estimation method (CEL 1979).

Fig 5.1. Frequency distribution of observed noise levels within the sampled TAFs of Phase 1.



containing the twenty randomly-sited measurements. The data presented have been normalised with respect to windspeed through application of the empirical 'windspeed-noise' model described in section 5.4.1.

The null hypothesis is tested by applying the classical 'analysis of variance' F-test to this data set. The rationale of the test is to compare two estimates of the variance of the total population of noise levels over the study area, the first (termed 'B') based on the observed variance of the means of the nineteen TAE samples, and the second ('W') based on the variance of the observations within the samples.If the null hypothesis holds, then the two estimates should not be statistically significantly different; if on the other hand B is significantly higher than W then the null hypothesis must be rejected since the statistical evidence is that the samples do not all come from the same parent population. The inference from this is that a significant proportion of the total spatial variance of noise levels over the study area is to be explained by differences existing between TAE types.

If the data summarised in Figs. 5.1(a) and (b) are tested directly however, the F-ratio ($\frac{B}{W}$) merely tests whether or not the nineteen <u>TAE zone samples</u> come from the same parent population. In order to make the above inference that any difference between sample populations is due to differences existing between the <u>populations of different TAE types</u>, it is necessary to assume (i) that the observed variance (B) between the sample means is an unbiased estimate of the variance existing between the means of the TAE type populations, and (ii) that the observed variance (W) within the samples is an unbiased estimate of the variance within the TAE type populations. In both cases the assumptions cannot be upheld unless B and W are corrected for biases arising in the collection of the data. Firstly, the fact that each TAE was sampled within a single day and all TAEs were samples on different days lead to a sampling bias since general temporal changes in noise levels were observed between days; the resulting observed value of B therefore includes an extra element of variance due simply to temporal between-day variations. Although the normalisation of data with respect to wind removed some of this additional variance, the analysis of Phase 3 data discussed in section 5.3.2 shows that unexplained between-day variance still existed. Appendix B shows how this variance was quantified and deducted to give a corrected estimate of between - TAE-type variance B'. The observed value of W is derived from measurements sampled from within single TAE zones. If, as was observed in this study, the variance within a single TAE zone is not a random sample of the variance existing within the population consisting of all zones of the same type, then the observed value of W will be reduced through the omission from the sample of that amount of variance which occurs between TAEs of the same type. Appendix B shows how, using a statistical analysis of the Phase 2 survey results, this variance was quantified and added to give a corrected estimate of within-type variance, W'. The correct test[1] of the null hypothesis is then conducted upon the F-ratio $(\frac{B'}{W'})$. Table 5.1 shows the corrected and uncorrected values of F for UNL and LNL, from which it is seen that the values of the ratios are so high that the corrections make little numerical difference, and therefore the resulting F-values are very robust. Correction is nonetheless necessary if a valid test of the hypothesis is to be made.

Table 5.1 Observed and Corrected Values of F for UNL and LNL

	Observed F	Corrected F'
UNL	15.64	14.78
LNL	29.89	28.70

1. Other statistical assumptions, of population normality and homogeneity of variance, are also required if the test is to be valid; these assumptions are discussed in Appendix B.

For the appropriate (18 and 361) degrees of freedom, F-values above 1.98 are significant at the 1% level - in other words there is a 99% probability that an observed F-value above 1.98 is due to a significant difference in the populations from which the samples were drawn. Comparing this with the F-values obtained from the empirical case study it is conclusively evident that the null hypothesis must be rejected; consequently therefore the TAE hypothesis was taken to be validated.

5.2.3 Calibration of the TAE Prediction Model

The objective of the model calibration exercise was to associate each TAE type with representative indicator values. Assuming that the urban areas within TAE types encompass normal statistical populations of indicator values, then the mean and variance can be considered as the appropriate representative parameters.[1] The TAE prediction model then becomes a method for predicting the 'area-mean' indicator values for any given TAE, within an accuracy defined by the confidence intervals which are determined by the population variances.

The mean indicator values for each TAE type were obtained directly from the normalised Phase 1 sample data summarised in Figs. 5.1(a) and (b), consisting of the means of the twenty spatially random measurements in each sample TAE. These 'area-means' are presented in the TAE matrix format in Table 5.2; this matrix therefore constitutes the calibrated TAE prediction model. The accuracy of the predictions is estimated by considering the spatial variation of indicator values both within TAE zones and between zones of the same type. Section 5.3.2 describes the statistical analysis

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1. An interesting statistical alternative is suggested in the study by PRICE (1972), involving the use of 'population percentiles'; for example the value of 'A_{10}' describes the indicator value exceeded over 10% of the 'population' area.

Table 5.2 Matrix of the TAE Prediction Model for Ambient Noise Indices UNL, LNL and (L_{eq})

LAND USE	ROAD NETWORK DENSITY		
	A. Dense	B. Medium	C. Sparse
	UNL, (L_{eq}) LNL	UNL, (L_{eq}) LNL	UNL, (L_{eq}) LNL
0. Residential	59.6, (55.8) 48.6	56.5, (53.0) 45.7	53.3, (49.6) 43.1
1. Industrial	62.6, (59.4) 54.1	63.1, (60.6) 56.6	*
2. Commercial	70.6, (67.7) 62.7	*	*
3. Open Space	*	*	46.3, (43.1) 39.7
4. Res/Ind	65.1, (61.9) 56.1	61.8, (60.4) 54.9	*
5. Res/Comm	57.4, (54.7) 50.4	58.4, (54.9) 47.5	60.2, (57.1) 51.9
6. Ind/Comm	69.7, (66.2) 59.5	66.8, (64.2) 60.1	*
7. Res/O.S.	59.4, (56.1) 49.6	54.7, (51.8) 47.2	51.6, (48.8) 44.4
8. Ind/O.S.	*	64.7, (63.3) 61.8	56.3, (53.9) 50.3

Key: UNL (equivalent to L_{10}) = Area-mean UNL (dBA)

LNL (equivalent to L_{90}) = Area-mean LNL (dBA)

L_{eq} = estimated area-mean L_{eq} (dBA)

* = Insignificant proportion (less than 0.5%) of total WMMC area in the category

of data from Phases 1 and 2 which led to the determination of a pooled estimate of the accuracy expressed in terms of general standard errors of estimate for UNL and LNL, from which confidence intervals were derived. The resulting standard errors for UNL and LNL respectively were 1.8 dBA and 1.6 dBA, giving 95% confidence intervals of 3.5 dBA and 3.1 dBA. Thus the accuracy of the model predictions given in Table 5.2 should be interpreted in terms of a 95% probability that the 'area-means' for any given TAE zone will lie within ± 3.5 dBA of the UNL prediction, and within ± 3.1 dBA of the LNL prediction. Note that the spatial variability in noise levels that occurs within any given TAE zone means that the error in using the TAE prediction model to predict noise levels at any given site within a TAE is much higher than this, as shown in section 5.4.2. L_{eq} was estimated and not measured directly, and it is not possible to quantify the accuracy of the L_{eq} prediction because the indicator estimation error is unknown.[1] However it is not unreasonable to suppose that the sampling error would be of the order of that shown by UNL and LNL.

The prediction model shows considerable differences in noise levels between the various land use types and between the network density categories, following a broad pattern which accords with the expectations of contemporary knowledge and theory. The results are compared with those of other studies in section 5.5.3 and the nature of the area types in relation to their predicted noise levels is discussed in section 5.5.2. The most immediately evident anomalies are to be found in the comparison of types 1A and 1B, and types 5A, 5B and 5C, as shown in Table 5.2. The

1. This is principly because the shape of the temporal distribution functions at each site is not known. The same limitation applies throughout the statistical analysis, which is why L_{eq} has not been included in it.

former case is possibly explained by the fact that heavy industries (steelworks for example) which emit high noise levels and generate much 'heavy goods vehicle' traffic, tend to locate in the 'medium' rather than the 'dense' network categories. There is a less clear explanation of the latter case, and it seems more likely that the apparent increase in noise levels with decreasing network density is due to statistical variation rather than a significant difference in conditions. Considering the model error of estimate it is seen that the noise levels of the three area types are not actually statistically significantly different.[1] This brings forward an important consideration in relation to the use of the prediction model. The model ostensibly allows the noise levels of any TAE to be predicted from knowledge of its TAE type; but at the same time the error of estimate imposes a limitation upon the model's ability to state that the noise levels of any one TAE type are definitely statistically different from those of another. Section 5.5 discusses the need in the mapping context to 'group' TAEs in order that the model might state with more confidence that the noise levels of one group of area types are significantly different from those of another group. This grouping is thus effectively a widening of the metric resolution level of the model - precisely as was described from a more theoretical perspective in Chapter 3.4. In the choropleth mapping application therefore, where it is necessary to display an <u>explicit distinction</u> between the conditions of one area and another, grouping is therefore necessary before the model can be reliably applied. The basic TAE prediction model of Table 5.2 may however be used in the <u>aggregate</u> appraisal of spatial conditions as expressed in a <u>cumulative frequency distribution</u>, since the concept

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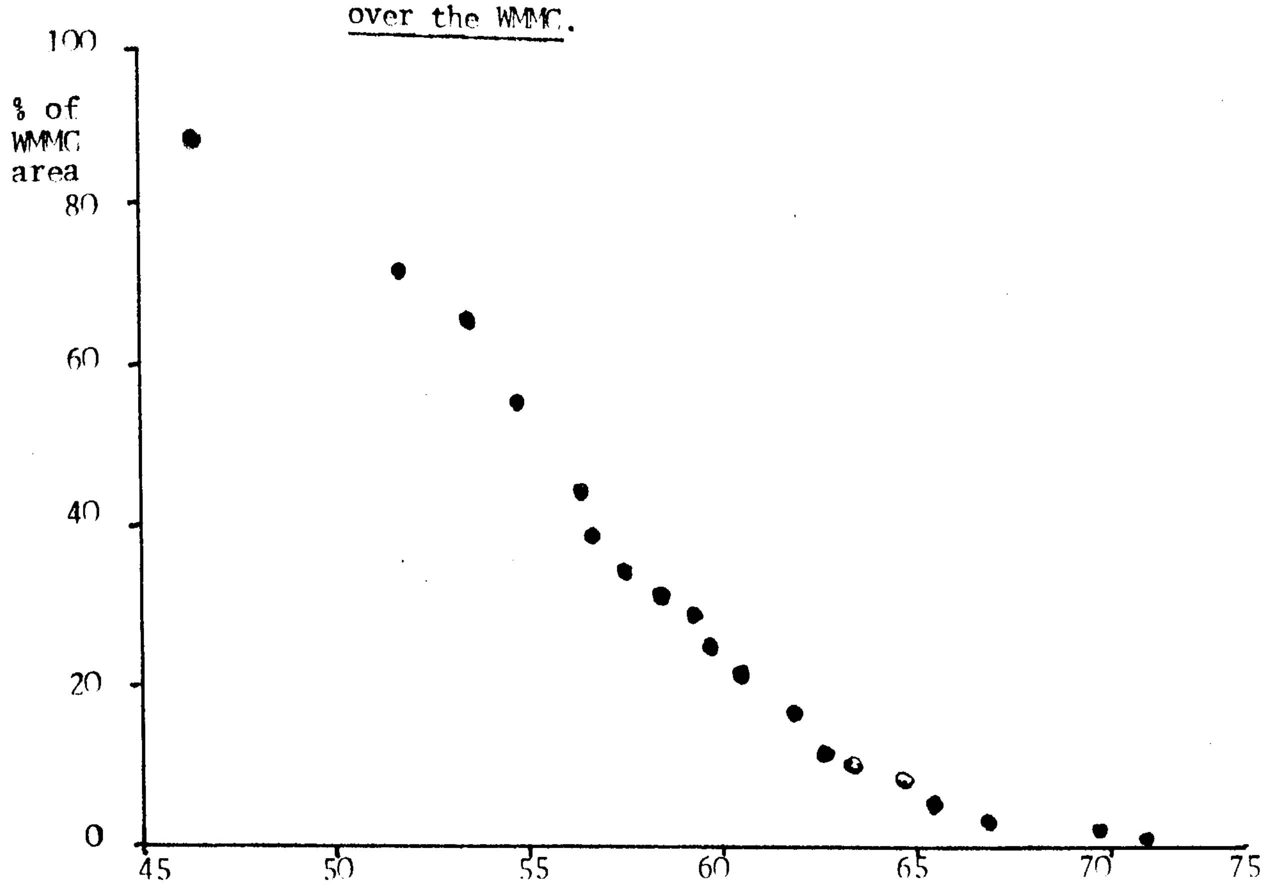
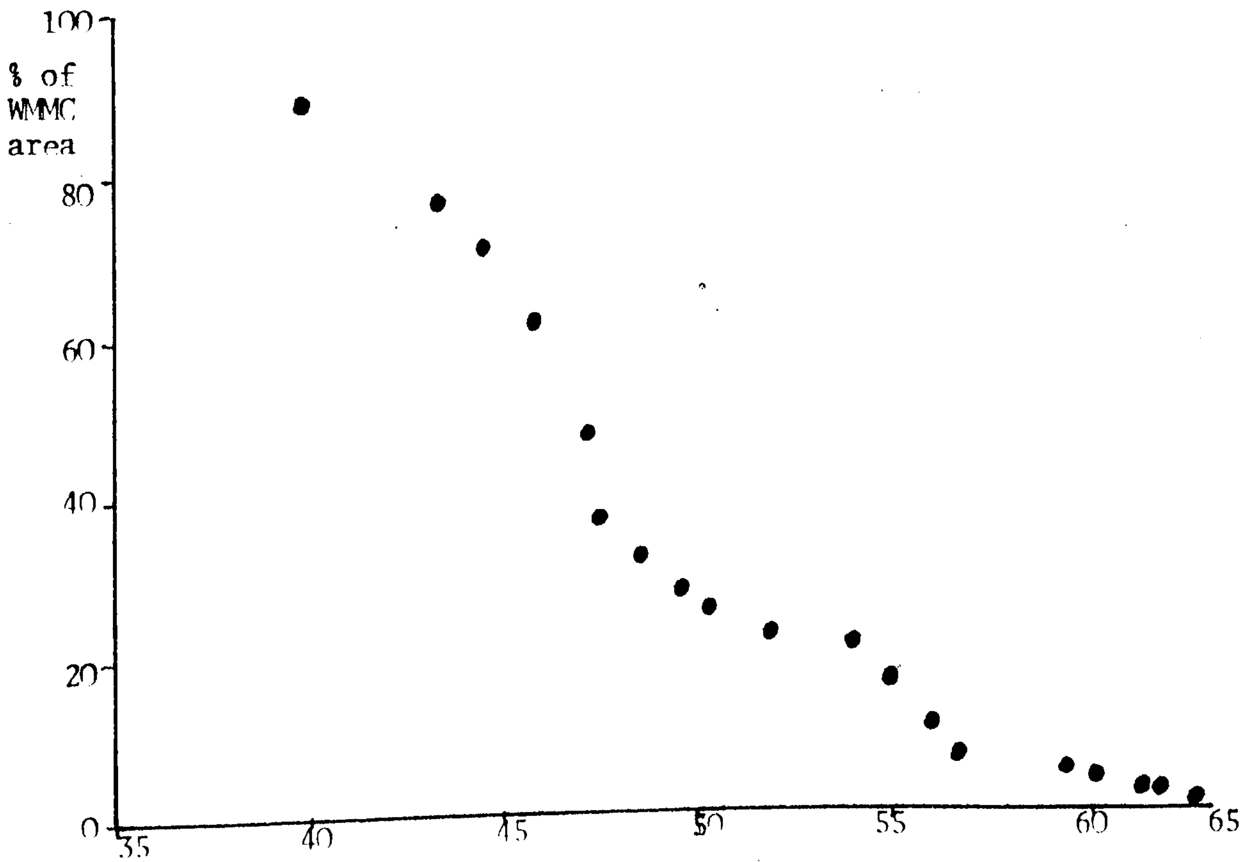
1. This is tested through the 't-test' as described in section 5.5.1.

Fig. 5.2 Cumulative frequency distribution of ambient noise levels over the WMMC.



(a) UNL Noise Level



(b) LNL Noise Level

involved is one of a continuum of conditions and it is not necessary to maintain that statistically significant differences exist between each item of data. Figs. 5.2(a) and (b) show cumulative distributions for each indicator obtained from a direct comparison of Table 5.2, and Table 4.4 which shows the population of the total WMMC land area in each TAE type. These cumulative frequency distributions constitute a 'legitimate' application of the TAE prediction model to an assessment of the overall ambient noise condition of the WMMC, and may be used for instance to determine the proportion of the WMMC study area over which a given noise 'threshold' or criterion level is exceeded. The 'grouping' of TAEs, which has been seen as theoretically necessary before the TAE prediction model may be applied as a valid mapping method, is also required in order to facilitate (i.e. simplify) the display, as discussed in Chapter 3.4 and pursued in Section 5.5.1.

This section has described the validation of the TAE hypothesis and the calibration of the TAE prediction model, and estimates of the model's accuracy have been given. The final objective in the testing of the TAE mapping methodology (the application of the model as a mapping method) is discussed in section 5.5. Prior to this however, the next two sections describe the much-referenced measurement method and statistical analysis procedures which enabled the tests and calibration to be performed validly and led to other advances in theoretical knowledge.

5.3 TECHNIQUES FOR COLLECTION, ANALYSIS AND INTERPRETATION OF DATA

The main issues in the collection of data were identified in section 5.2.1 as (a) the measurement method, (b) the sampling density, and (c) sample site location. The issues concerning the statistical analysis and interpretation of data to facilitate the hypothesis testing and model calibration stages involve an investigation of both spatial and temporal variance.

This section discusses data collection and data analysis issues in turn.

5.3.1 The Collection of Data

(a) The measurement method

The points at issue are the choice of the survey technique for the measurement of the noise indicators, and the sampling period.

As already observed, the requirement in urban ambient noise surveys for a large number of observation sites imposes severe restrictions of economy in relation to the survey and sampling technique employed (PRICE 1972). Consequently, "economy steps may involve reduction of observation time periods or the use of measurement equipment less complicated than statistical analysis gear (sic)" (SCHULZ 1972), and ambient surveys have customarily used short-term, 'manual' statistical sampling techniques using a simple moving-needle sound level meter (PRICE 1972, GILFORD and NORRIS 1973, YERGES and BOLLINGER 1973, SCHOLES and SALVIDGE 1973, LABRECHE, MENDIAS and PUTNICKI 1976, ATTENBOROUGH et al 1976, PRABHU and CHAKRABORTY 1978).

Two possible methods, termed the 'continuous' and the 'discrete' approaches, may be used. The 'discrete' method is simply a 'slow-motion' equivalent of the statistical sound level meter, which stores sound level observations at approximately 0.1 sec. intervals and makes a statistical analysis of the resulting distribution of observations over the sample period. In the manual technique the surveyor records the instantaneous sound levels occurring at intervals of 3-10 sec. and makes a statistical analysis of the results obtained usually over a 3-5 min. sample period. In the 'continuous' method, the surveyor observes the movements of the meter needle for a sample period and then visually estimates certain parameters, for example, "the mean value together with the upper and lower extremes" (PRICE 1972); "the value of L_{90} on a subjective basis" (GILFORD and NORRIS 1973); and "the typical low or mean minimum" (ATTENBOROUGH et al 1976, BRITISH STANDARDS INSTITUTE 1967). This research adopted the technique of PRICE (1972), in which the surveyor "observed the needle of a sound level meter set on 'slow' response for a period of 15 sec and visually estimated ... the upper and lower extremes. This was repeated 10 times so that 10 samples were obtained at each measurement location extended over a period of 3-5 min" (PRICE 1972). The arithmetic means of the ten sampled upper and lower extremes gave two parameters of the noise distribution which were termed the 'Upper Noise Level' (UNL) and 'Lower Noise Level' (LNL). In this research the sampling was conducted over a five minute period as illustrated in Fig. 5.3(a), and the survey technique (described in Appendix A) allowed a second measurement to be made at each site approximately 30 minutes after the first; consequently each site was represented by the 'site-mean' indicator values obtained by averaging the two measurements sampled over a total period of ten minutes. The sampling error is discussed in Appendix B. An empirical study (also described in Appendix B) was conducted which showed that the mean difference between these indicators and simultaneous (tape analysis) recordings of the percentiles L_{10} and L_{90} was in each case 0.2dBA, with standard errors of 0.3 dBA and 1.1 dBA respectively. Thus in neither case was the mean difference statistically significant[1], while the standard error was small compared with other sampling errors (discussed in section 5.3.2). The research therefore supported the suggestion of MOCHIZUKI (1969), that "an approximation of the L_{10} and L_{90} levels could be obtained from the arithmetic average of the upper and lower extremes" (cited in PRICE 1972); both ATTENBOROUGH et al (1976) and WYLE LABORATORIES (1972) have also

1. Significance was examined through a t-test at the 5% level.

Fig. 5.3(a) Diagram showing derivation of UNL and LNL measures.

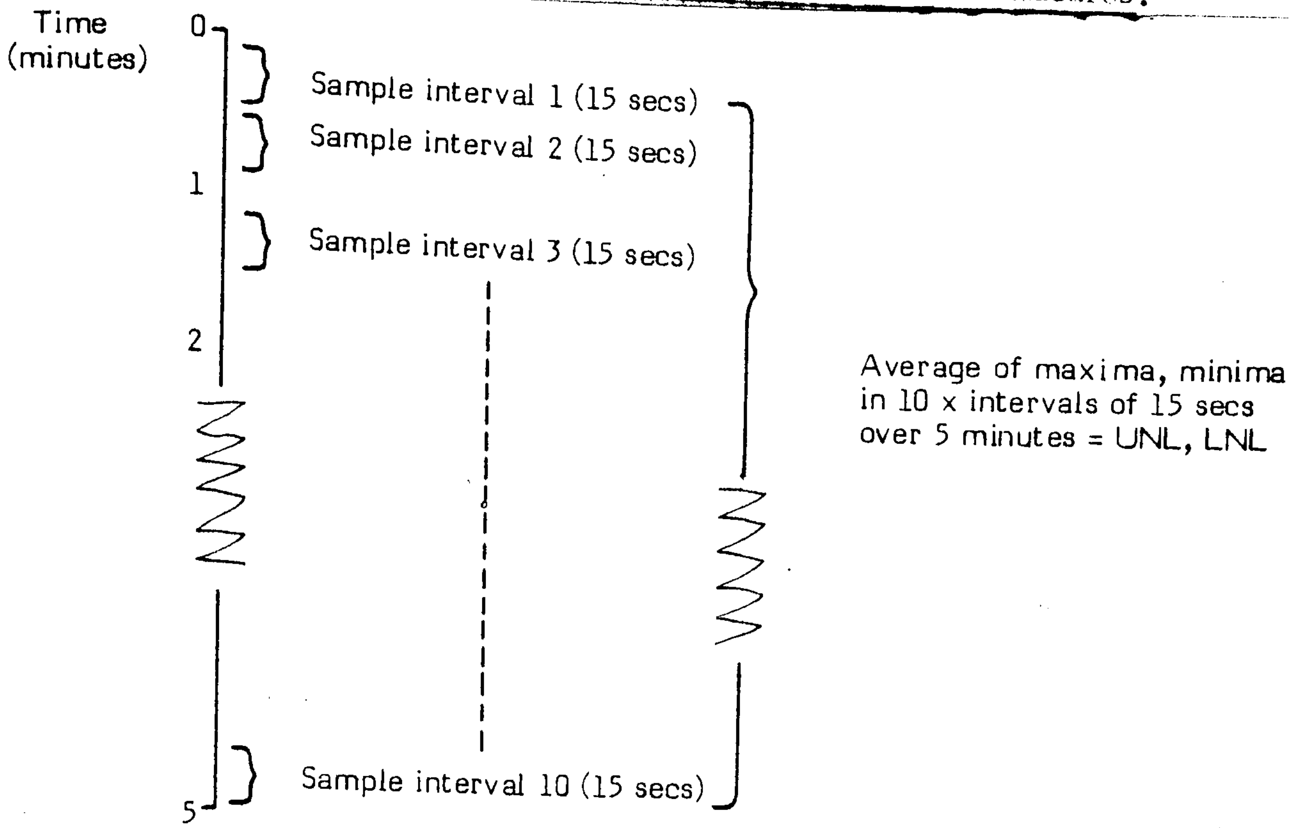
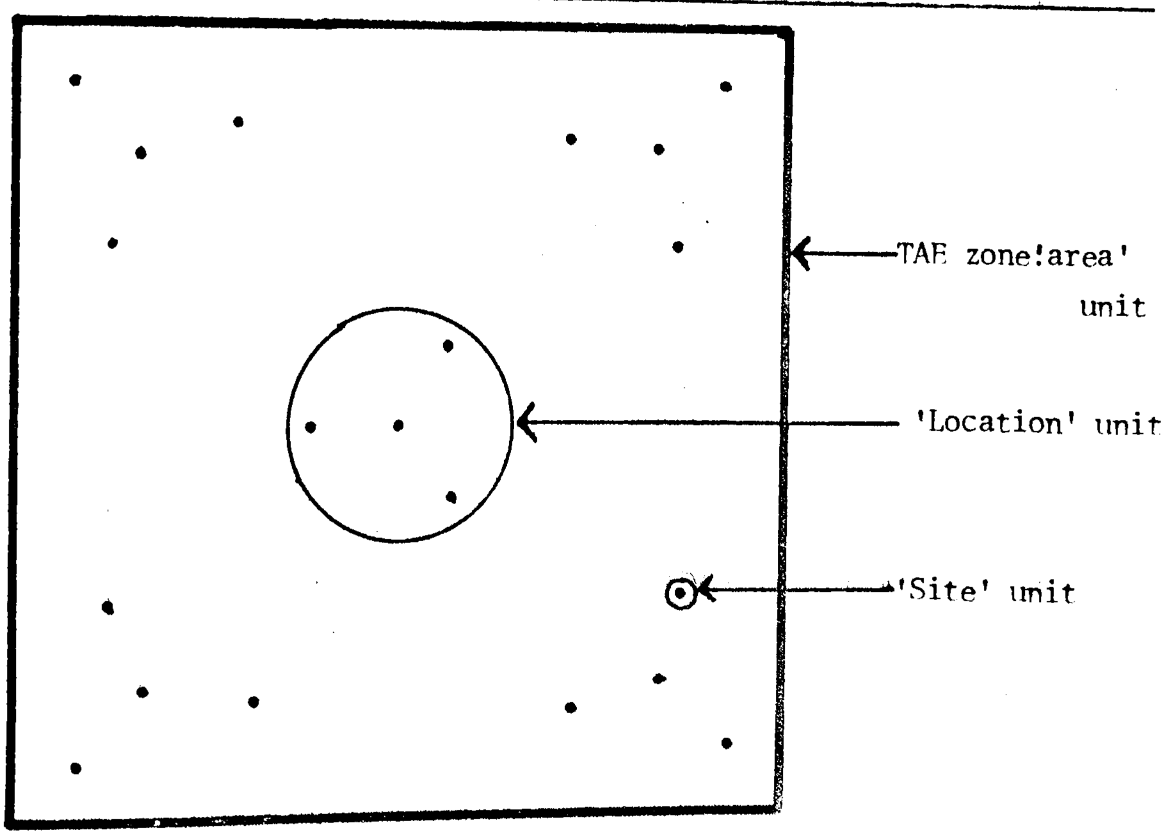


Fig. 5.3(b) Spatial distribution of sample sites within a sample TAE



suggested that percentiles may be estimated in this way.

The advantages of this technique lie mainly in the use of robust, cheap, lightweight equipment likely to be already available in any environmental study unit. Of the alternatives, tape techniques would have been cumbersome for the surveyor and time-consuming in analysis, while the one statistical sound level analyser available was limited to measuring only one index at a time. Contemporary developments in instrumentation now allow precision grade measurements of L_{eq} to be made with hand-held statistical sound level meters (CEL 1979), and it is recommended that these be used in future surveys so that an accurate measurement of a standard indicator can be obtained, together with the UNL and LNL as estimates of the percentiles.

In this research UNL and LNL were interpreted directly as being equivalent to the percentiles; the thesis persists with the UNL/LNL terminology however in order to maintain a strictly accurate account. As stated the L_{eq} was also estimated, through an approximation method involving the assumption of a normal statistical distribution of noise levels within the sample period. If this assumption holds then the parameter $(L_{10} - L_{90})$ may be used to estimate the standard deviation of the distribution; standard tables may then be used to achieve an approximation of the distribution in terms of a histogram of noise level intervals each with a relative frequency and mean noise level. The histogram is re-expressed in an algorithm for estimating the L_{eq} as described by CUNNIFF (1977)[1]. It is not possible to determine the accuracy of this estimation method since

1. The algorithm for estimating L_{eq} is given by:

$$L_{eq} = 10 \log_{10} \left(\frac{1}{100} \left(\sum_{i=1}^{N} f_i . 10^{Li/10}\right)\right)$$

where f_i = relative frequency of interval i (%)
L_i = mean noise level of interval i
N = total number of intervals into which the distribution is divided.

(CUNNIFF 1977)

there is insufficient knowledge of the extent to which the assumed normal statistical distribution of noise levels within the sample period actually obtains in the various different types of noise environment surveyed, nor of the magnitude of the error that results if the distributions depart from normality. Consequently it was not felt that sufficient confidence existed in the accuracy of the estimation method to allow a detailed appraisal of the temporal and spatial variance of L_{eq} to be made.

(b) Sampling density

The choice of an appropriate sampling density is dependent upon the spatial variability of the noise conditions and the desired accuracy in the spatial mean noise level. Chapter 3 has shown that the latter issue has a relationship with the policy context; in the generalised context of this research it was decided to follow the guidelines set by SENKO and KIRSHNAN (1971). In their study of New York it was estimated that L_{90} values showed a standard deviation of 5 dBA within 1 sq. mile "homogeneous sampling units", and that consequently if values were normally and randomly distributed within the unit, a sampling density of 25 sites per sq. mile would lead to an observed mean L_{90} for which there would be a 95% probability that the actual area's population mean would lie within plus or minus 2 dBA. SAFEER (1973) has added however that "better information is required as to the statistical distribution of sound levels in different types of environment", and indeed this research was able to contribute further knowledge in this field, as described in section 5.4.2. In general the results substantiated the estimates of SENKO and KIRSHNAN (1971), showing standard deviations of 7 dBA and 5 dBA for UNL and LNL respectively. In (correct) anticipation of a higher degree of spatial variance for L_{10} than for L_{90} (since L_{10} is more dependent upon local sources than L_{90}), the research was conducted using a sampling identity of 20 sites per TAE (equivalent to 33 sites per sq. mile) with the intention of maintaining

2 dBA confidence intervals for UNL; this is seen in section 5.3.2 to have been for the most part successful.

(c) Location of the sample sites

Sample sites may be located on either a random or a deterministic basis (SAFEER 1973). Deterministic siting is of course necessary where particular sources (a motorway for example) are to be investigated, but ambient studies have tended to take the random approach since this is consistent with the assumption of within-zone homogeneity and results in a statistical sample distribution from which area population parameters may be inferred. Sites are commonly selected at the nodes of a grid overlaid upon the study area (e.g. GILFORD and NORRIS 1973, TOKYO METROPOLITAN GOVERNMENT 1976, PRABHU and CHAKRABORTY 1978), although occasionally a deterministic sample may be added (e.g. BENEDETTO and SPAGNOLO 1977). A purely random technique was adopted in the research, with sites selected from a stratified sampling grid as shown in Fig. 5.3(b), giving two levels of spatial analysis, the 'location' and the 'area' (TAE zone). This subdivision of the spatial unit was found to be useful in the analysis of the data, as discussed in the sections following. Thus the individual 5-minute observations of UNL and LNL were therefore averaged in three stages: (i) the average of the two five minute observations led to 'site-mean' values of UNL and LNL; (ii) four site-means were averaged to give 'location-mean' values of UNL and LNL, and (iii) five location-means were averaged to give 'area-mean' values of UNL and LNL. Appendix A gives details of the actual conduct of the survey technique.

5.3.2 Statistical Analysis and Interpretation of Data

It was seen in section 5.2 that the TAE mapping methodology is based upon the assumption of nineteen 'TAE type' populations of noise levels. Each population is understood to consist of the noise indicator values representative of every point in all the TAEs of that particular type within the study area; the 'representative indicator value' at any given point being the value that would be obtained by monitoring noise levels there throughout a long (theoretically infinite) series of working weekdays. In the research the parameters of these populations were estimated from sample data, and therefore both spatial and temporal sampling errors were involved whenever they were applied in testing and calibration exercises - for example using the sample mean as an estimate of the population (TAE type) mean in the prediction model. The quantification of these errors of estimate was seen in section 5.2 to be necessary in order (i) to correct the data to allow a valid, unbiased test of the hypothesis to be made, and (ii) to specify the accuracy of the prediction model. Section 5.4.2 shows that in addition a useful contribution to contemporary theoretical knowledge of urban ambient climates is made through the development of a model for predicting the effect of windspeed on ambient noise levels and the discovery that spatial and temporal variances are related both to each other and to the TAE type of the area in which they are observed.

Both the spatial and the temporal errors of estimate contain several components, deriving from different (hierarchical) sources of variance. Through a statistical analysis of the data from all three survey phases, and making the assumptions of normality and independence in each source of variance, the results shown in matrix form in Table 5.3 were obtained for the temporal (i) and spatial (j) elements. The matrix shows the components of variance (expressed as standard deviations, $c_{i,j}$) due to each component 'source' i,o and j,o, and the standard errors $\sigma_{i,j}$ which result from the compounding of the component variances. The standard errors therefore describe the error involved in using the observed 'area-mean' of a given sample TAE to represent the mean of the population given by i and j, where i and j are defined below. The spatial elements are illustrated by

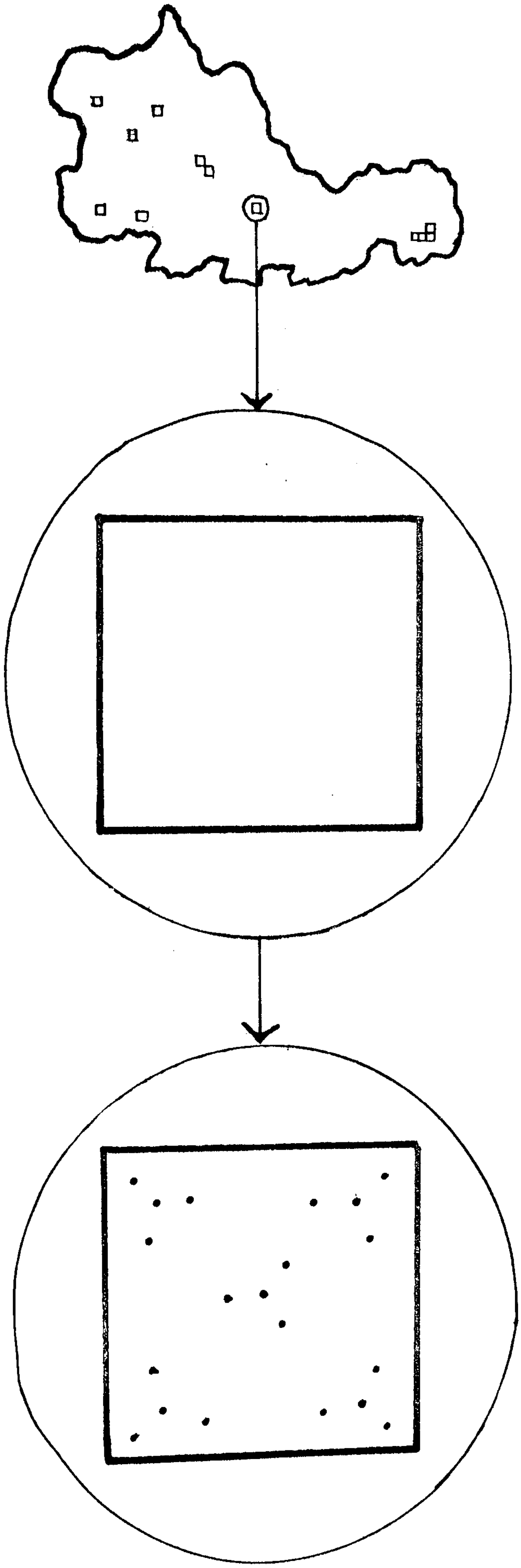
SPATIAL VARIATION \ TEMPORAL VARIATION		Within-day i = 1	Between-day (Wind-normalised) i = 2	Between-day (Not normalised) i = 3
		$c_{1,0}$ 0.30 0.18	$c_{2,0}$ 0.48 0.98	$c_{3,0}$ 0.89 1.95
Sample Sites, sample TAE j = 1	$c_{0,1}$ 0.00 0.00	$\sigma_{1,1}$ 0.30 0.18	$\sigma_{2,1}$ 0.57 1.00	$\sigma_{3,1}$ 1.06 2.19
All sites Within sample TAE j = 2	$c^*_{0,2}$ 1.55 1.17	$\sigma_{1,2}$ 1.57 1.18	$\sigma^*_{2,2}$ 1.69 1.55	$\sigma^*_{3,2}$ 1.99 2.68
All sites, all TAEs (of same type) j = 3	$c^*_{0,3}$ 0.53 0.41	$\sigma^*_{1,3}$ 1.68 1.25	$\sigma_{2,3}$ 1.76 1.59	$\sigma^*_{3,3}$ 2.06 2.71

Code: UNL standard deviation (dBA)   LNL standard deviation (dBA); Upper figure = UNL, Lower figure = LNL

* Values estimated assuming r.m.s. addition of variances

Table 5.3 Matrix of Temporal and Spatial Variation in Noise Levels, Showing Component (c) and standard error (σ) Elements, (dBA; pooled Data for all TAEs)

Fig. 5.4 Diagram showing the hierarchy of the spatial sampling procedure.



(a) Take population of TAEs of a given type within the WMMC (j_3).

(b) Sample of one TAE of a given type (containing an infinite population of sites) (j_2).

(c) Sample of 20 sites distributed within the sample TAE (j_1).

reference to Fig. 5.4 which shows the spatial sampling procedure: j = 1 refers to the 'population' consisting of the twenty sample sites within the sample TAE; because each of these is observed, the component of sampling variance $C^2_{0,1}$ is zero; j = 2 refers to the 'population' consisting of all points within a given sample TAE, and hence $C^2_{0,2}$ is the sampling (error) variance incurred in using the mean of the 20 sample sites to represent the mean of all points in a given sample TAE; j = 3 refers to the 'population' of all points within all TAEs of the same type, and $C^2_{0,3}$ is therefore the additional component of variance which exists between TAEs of the same type. The temporal elements may be similarly described: i = 1 refers to the population of noise levels within any single working weekday, and the error variance $C^2_{1,0}$ is that involved in using the observed area-mean to represent the mean that would be obtained if each of the 20 sites had been monitored throughout the day; i = 2 refers to the population of noise levels over an indefinite period of days, but with the effects of wind removed through normalisation, and consequently $C^2_{2,0}$ is the additional variance that occurs between days due to factors other than wind; i = 3 refers to the long-term population including the effects of wind, and so $C^2_{3,0}$ refers to the between-day variance caused specifically by variations in windspeed.

The components $C_{i,j}$ and sample errors of estimate $\sigma_{i,j}$ are derived from the assumption of additive variances, described by the general relation:

$$\sigma_{n,m} = \sqrt{\sum_{i=0}^{n} C^2_{i,o} + \sum_{j=o}^{m} C^2_{o,j}} \qquad \text{———— 5.1}$$

and the resulting values of $\sigma_{i,j}$ in the matrix are dependent upon the assumptions of normality and independence, an issue which is discussed in Appendix B together with the method for treating the survey data. The Appendix also shows that the instrumental error is negligable. The figures in the matrix refer to 'pooled' data representing all TAE types taken together. In the cases of the components $C_{1,0}$ and $C_{0,2}$ however, the survey data enabled the values for each TAE type to be calculated. The results are presented in Tables 5.6 and 5.7 in Section 5.4.2, where it will be shown that a variation in variances is evident, and that this is related to TAE type.

The elements in the matrix were used in the testing and calibration exercises; in particular, it will be noted that the parameter $\sigma_{2,3}$ describes the standard error of estimate in using the observed 'area-mean' of a given TAE, measured on a single survey day, to represent the mean of all points in all TAEs of that given TAE type over a long-term period, assuming normalisation for windspeed. It was this parameter that was used as an estimate of the standard error of the TAE prediction model values given in Table 5.2. Appendix B describes the use of other elements in the matrix to allow the corrections to the F-test to be made. The matrix also shows that there is an acceptable degree of consistency in the magnitudes of the spatial and temporal sources of error variance, from which it may be concluded that the spatial sampling density and the temporal sampling period are mutually consistent.[1] The temporal sampling error components (the 'i' dimension in the matrix) show that, while LNL is more stable than UNL within any given day, the LNL is prone to more between-day variance than the UNL, and particularly to that resulting from windspeed changes. This is offset in the spatial dimension (the 'j' dimension in the matrix) by the fact that UNL appears to be more spatially variable than LNL, with the greatest variance occurring for both indicators over a spatial scale smaller

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1. If for example the spatial error had been considerably larger than the temporal error, it would have been possible to increase the general efficiency of the survey technique (while still maintaining the same resource committment) by increasing the sampling density at the expense of the sampling period until the error magnitudes were similar.

than the TAE unit. As a result the crucial error of estimate $\sigma_{2,3}$, the values of which have already been quoted in section 5.2.3 as describing the accuracy of the prediction model, gives error values for the two indicators which are approximately the same. This observation leads to the general conclusion that as a method of model calibration, the survey technique performs equally well for UNL and LNL.

5.4 OTHER CONTRIBUTIONS TO THEORY

While the general methods for quantifying the elements in the variance matrix are described in the Appendix B, two areas of analysis are discussed here because they make something of a contribution to theoretical knowledge of ambient noise climates. Firstly, an original empirical model for predicting the effects of windspeed upon ambient noise was developed; secondly the spatial and temporal variances characteristic of the TAE types were analysed in order to further knowledge of the nature of ambient noise climates in different types of area.

5.4.1 An Empirical Windspeed-Noise Model

The model was developed as part of the study of between-day variation in noise conditions, in order to 'normalise' noise measurements to a standard 'light wind' condition, and thereby to allow 'area-mean' noise levels observed on different days (with different windspeeds) to be compared. This comparison was essential both in the F-test of the TAE hypothesis and in the calibration of the TAE types in the prediction model. The data used for this was for the assessment of between-day variation were obtained from the Phase 3 'return' surveys of seven TAEs, plus the data obtained on the original visits to these TAEs in Phases 1 and 2, thus involving 140 sites at which noise levels had been observed on two different days separated by an interval varying from two to six months. On each occasion the noise levels were measured and a Beaufort scale estimate of the windspeed was made.

The empirical model was based upon the hypothesis that the observed differences in noise levels between the two survey days could be explained by the observed differences in windspeed. A proper mathematical specification of a model based upon the theoretical properties of wind-generated ambient noise was not possible given the current paucity of knowledge in this field (although a speculative theoretical approach is discussed shortly). Consequently an empirical model was derived under the following assumptions: (i) that for any given ambient noise level, the windspeed measured in Beaufort Scale units is linearly related to a numerical increase in the ambient **noise** indicator value; (ii) that the Beaufort Scale is a ratio scale of windspeed, so far as this effect is concerned; (iii) that windspeeds at or below force 2 have no effect on noise levels and can be put equal to a standard 'light wind' condition, and (iv) that for any given windspeed, the numerical increase in the indicator value will depend on the level of ambient noise existing in the absence of wind, being highest in cases where these noise levels are low and lowest in cases where these levels are high.

Appendix B describes the model development and calibration technique involving the use of regression analysis. This resulted in the following empirical models for UNL and LNL; they predict the numerical increase in the indicator values (dN_{UNL}, dN_{LNL}) due to the wind factor (w), where the observed indicator values are UNL and LNL, and $w = W-2$ for Beaufort Scale values $W \geq 2$, and $w = 0$ for $W < 2$.

$$dN_{UNL} = 0.15w\left(\frac{75-UNL}{10}\right)^2 \qquad \text{——— } 5.2$$

$$dN_{LNL} = 0.13w\left(\frac{75-LNL}{10}\right)^2 \qquad \text{——— } 5.3$$

It has been stated that the main use of the windspeed-noise models was in the normalisation of the observed noise levels to a standard 'light wind' condition. This involved subtracting the predicted value dN from the observed indicator values; Table 5.4 shows the magnitude of these

Table 5.4 Windspeed-Noise Prediction Model: Corrections to be Subtracted from Observed UNL Values for Given Windspeed W to Obtain Normalised UNL Values

Observed UNL (dBA)	Windspeed W (Beaufort Scale) 0	1	2	3	4	5	6	7	8
75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	*	*
65	0.0	0.0	0.0	0.1	0.3	0.4	0.5	*	*
55	0.0	0.0	0.0	0.5	1.0	1.6	2.1	*	*
45	0.0	0.0	0.0	1.2	2.3	3.5	4.7	*	*
35	0.0	0.0	0.0	2.1	4.2	6.2	8.3	*	*

* Model not valid for W>6

N.B. To achieve normalisation to a standard 'light-wind' condition, the above values were subtracted from measured values of UNL for given observed values of W.

'correction values' dN for values of the observed windspeed W and the noise level UNL (the values for LNL are marginally smaller due to the smaller coefficient as seen in Eqn. 5.3). The accuracy of the models may be assessed through reference to the regression parameters given in Table 5.5, which describe the extent to which the predicted values dN were able to explain the observed variance of the noise levels between separate days. The table clearly indicates the increase in explanatory power which occurs as the spatial scale of the data is increased; for example, more than 90% of the variance between the TAE area-means observed on different days

Table 5.5 Regression Parameters from Empirical Calibration of the Windspeed-Noise Model

DATA SET	n	x	t	r	r^2(%)	r.e.(dBA)	K(dBA)
UNL site	140	0.152	8.63	0.59	36.8	2.52	-0.12
UNL location	35	0.123	5.57	0.70	49.0	1.48	-0.26
UNL area	7	0.143	6.51	0.95	90.2	0.58	0.02
LNL site	140	0.134	8.32	0.59	34.8	2.34	0.11
LNL location	35	0.153	11.56	0.89	79.2	1.53	-0.16
LNL area	7	0.169	7.90	0.96	92.2	1.00	-0.28

Key

n = number of independent samples
x = regression coefficient
t = student's t statistic
r = regression correlation coefficient
r.e. = residual error
K = regression constant

appears to be due to general effects of windspeed, while at the level of the individual site only some 35% of the observed variance may be explained in terms of windspeed. Much of the unexplained variance at the site level may be due to the directional effects of wind, acting independently of the speed; for example changes in wind direction, at constant windspeed, are likely to cause changes in the noise levels at any given site depending on whether or not the wind direction is such as to enhance or attenuate the sound emanating from the nearest sources. No particular attempt was made to study this effect however since the application of the results was to area-mean data, where it appeared that the random distribution of sites led to random directional effects which, when observations were averaged to obtain the area-mean, were reduced to very low levels of variance. The high explanatory power of the prediction model at the area-mean level is the more surprising for the fact that the Beaufort Scale Windspeed measurements were subjectively estimated (in accordance with the qualitative nature of the scale as shown in Appendix B) and represented the subjective averaging of windspeed conditions over the observation period, therefore inevitably involving error variance which would be expected to appear in the residual error of the regression. No estimate could be made of this source of error variance. The high explanatory power at the area-mean level should be viewed with caution however given the low number of independent observations available.

The possible theory behind the relationship between windspeed and the raising of ambient noise levels is speculative, little research having been undertaken on the matter. In general, workers have simply advised that surveying be discontinued when windspeeds exceed certain thresholds, for example 10m sec^{-1} (DOE, 1975)[1] and 10m hr^{-1} (PRICE, 1972)[2]. Two possible causes of windspeed noise are advanced in this research, although no empirical investigation was possible and the matter is treated at the level of a discussion.

Firstly, sound is produced by the wind-induced excitation of non-rigid objects, and the sound intensity increases with windspeed. The roaring of trees in a gale is an extreme example of this; more common is the rustling of trees, bushes, grass and garden foliage which tends to occur as the windspeed exceeds Beaufort Scale 2. A related phenomenon is the excitation of air passing round certain, especially rigid, physical forms; the 'whistling' caused by telegraph wires and the 'fluting' effect of building edges are examples of this (WALTERS 1978). Clearly the extent and intensity of the sound produced in these ways is dependent on the physical nature of the area in question - the presence and proximity of 'excitable' objects

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1. Equal to Beaufort Scale 3.

2. Equal to Beaufort Scale 5.

for example. Appendix B discusses a theoretical prediction model for this type of noise based on the kinetic energy of the wind.

A second causal factor has been considered, associated with the larger scale phenomenon of atmospheric sound refraction. The increase in sound levels downwind of a given source is common material in most basic acoustics literature (e.g. BOULIND, 1952, WINSTANLEY, 1952). This is normally assumed to be balanced by a compensating upwind reduction (BOULIND, 1952) but it appears that the quantitative balancing of increases and decreases has not been studied. There is therefore a possibility that a net increase of ground-level ambient noise may occur, in proportion to the vertical windspeed gradient. This would be the case if the planes of wind shear acted as partial reflectors of noise, causing a reduction in the vertical dispersion of sound into the atmosphere and, through reflection, a corresponding net increase in the sound levels observed at ground level. This proposition is effectively a generalisation of the phenomenon through which sound is reflected back to earth from 'pockets' of atmospheric turbulance (DELANEY 1977). Since vertical windspeed gradients have been shown to increase in proportion to ground-level windspeeds (CALDER 1973) due to air-ground friction, the degree of this effect would increase in proportion to windspeed, although the possible form of the relationship is obscure owing to the lack of knowledge in this field of atmospheric physics. Other factors may act to enhance the gradient; for example, NELSON and ABBOTT (1976) have shown that windspeed gradients are higher in urban areas than in rural areas, owing to the increased surface roughness friction resulting from buildings. The reflection effect may also be enhanced by the positive relationships between windspeed and general cloud cover that is quite well established (e.g. MARSH and FOSTER, 1967); in other words a band of denser, cloudy, humid and possibly rain-filled air at a level above the ground may also act as a partial sound reflector.

These arguments are put as possible physical explanations for the empirical relationships expressed in Equations 5.2 and 5.3. However since none of the theory is tested or specified mathematically the empirical models remain the only means for quantifying the effects of wind on ambient noise levels and therefore of allowing the empirical survey data to be normalised with respect to windspeed. It should be noted that despite the interesting and substantive theoretical issues involved, this latter purpose provided the underlying reason for undertaking the study of the relationship between windspeeds and ambient noise levels, in order that noise levels observed under different windspeeds could be properly compared.

5.4.2 Spatial and Temporal Variance in Ambient Noise in Different Types of Area

It has already been stated that ambient noise levels vary within individual TAE zones, and that the TAE 'area-mean' represents the mean of a sample of twenty sites which comprise a sample population whose variance is indicative of the variance of noise levels across the whole TAE. Table 5.6 shows the standard deviations of the twenty sample site-means in each of the TAEs surveyed in Phase 1. From the pooled values of these standard deviations it was concluded that the general within-TAE spatial variation in the noise levels of individual sites showed standard deviations of 6.9 dBA and 5.2 dBA for UNL and LNL respectively.[1] Spatial variation in UNL (i.e. L_{10}) does not appear to have been examined in contemporary research, but the value for LNL compares well with the value of 5dBA for L_{90}

1. Note that these values were translated into the component element $C_{0,2}$ in Table 5.3 by dividing by $\sqrt{20}$, since $C_{0,2}$ is the standard deviation of the 'area-mean' which itself consists of 20 sample 'site-means'.

Table 5.6 TAE Matrix Giving Standard Deviations of the Spatial Variations of UNL and LNL Values Observed at Sites Within TAE Zones (dBA)

LAND USE	NETWORK DENSITY		
	A. Dense	B. Medium	C. Sparse
0. Residential	7.45 4.51	7.42 5.13	7.78 3.66
1. Industrial	5.83 3.62	6.56 6.02	*
2. Commercial	4.69 4.26	*	*
3. Open Space	*	*	3.60 2.39
4. Res/Ind	8.11 5.86	5.73 4.19	*
5. Res/Comm	6.68 5.74	8.86 6.98	9.85 9.15
6. Ind/Comm	7.49 6.12	6.33 5.08	*
7. Res/O. S.	9.54 5.58	6.49 3.46	7.63 5.03
8. Ind/O. S.	*	3.86 3.16	6.44 6.07

Cell Codes: Upper figure = UNL Standard Deviation

Lower figure = LNL Standard Deviation

* = Insignificant proportion (less than 0.5% of WMMC area in the category

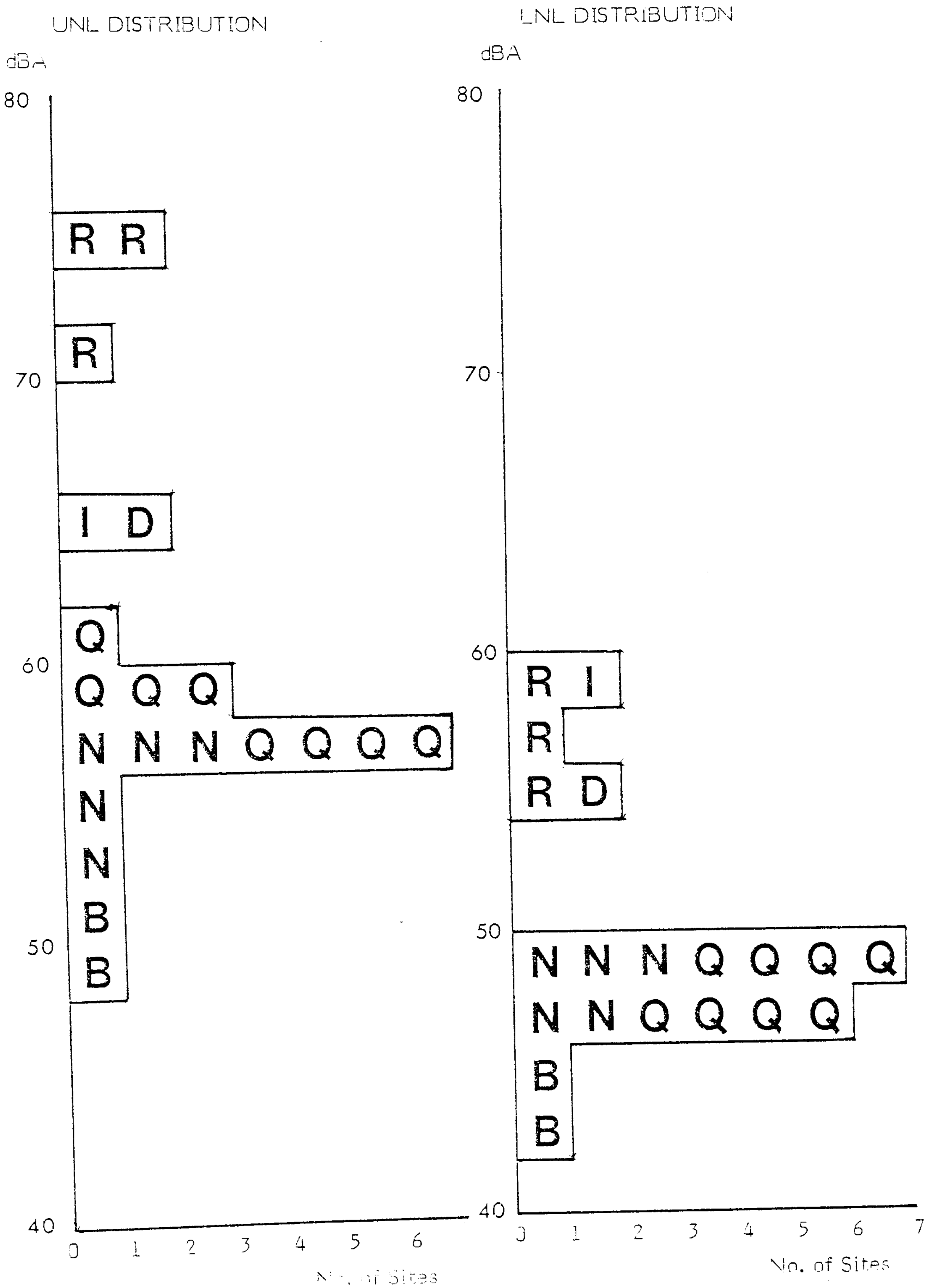
(N.B. Data normalised for windspeed).

assessed over 1 sq. mile zones in New York by SENKO and KIRSHNAN (1971).

These comparatively high levels of variance explain why the TAE prediction model, which predicts area-means, is an inaccurate method for predicting the noise levels of individual sites. In fact, if used to predict site-mean levels the model has 95% confidence levels of ±14 dBA and ± 10 dBA for UNL and LNL respectively. This is not a disadvantage in the context of a mapping methodology however since it is the area-means, rather than the site-means, that are required for the (choropleth) cartography. Indeed, this evidence reinforces the argument for the area-based approach to predicting and representing urban ambient noise as used in the TAE mapping methodology.

In other contexts (e.g. small scale studies) however, site-mean prediction is valuable, and the review of contemporary research in Section 5.1 showed that certain point-receptor prediction methods overcome the inaccuracies in using area-based parameters to predict the noise levels at individual sites, by the inclusion of a site-identity parameter in addition to the area-based parameters. Such was the method used by ATTENBOROUGH et al (1976) in their national survey of the UK. It was not considered necessary to make a detailed investigation of this modification in this research for the reasons stated above, but a case study of one TAE was made to assess the potential of the method for further research. The 'residential, dense network' TAE type (OA) was chosen for study since a wide range of sites (in terms of their proximity to the most prominent noise source) was provided, and such an area is fairly typical of urban areas in general in terms of spatial variability, noise source distribution and type. Each site was allocated into one of six categories of site, the distributions and nature of which are shown in Fig. 5.5. The diagram shows that the variability of the noise levels within each category is small compared with the variation within the whole TAE; strictly an F-test should be performed to assess the significance of the difference but since the sample was small and the relationship quite evident at the indicative level, this was not done. The evidence, albeit based on a single sample TAE, is therefore that if desired it would be possible to modify the TAE

Fig. 5.5 Distribution of site-mean noise levels in the case study TAE



R Within 10m of busy road

Q " " of quiet road

D " 30m facing busy road

N Within 30m facing quiet road

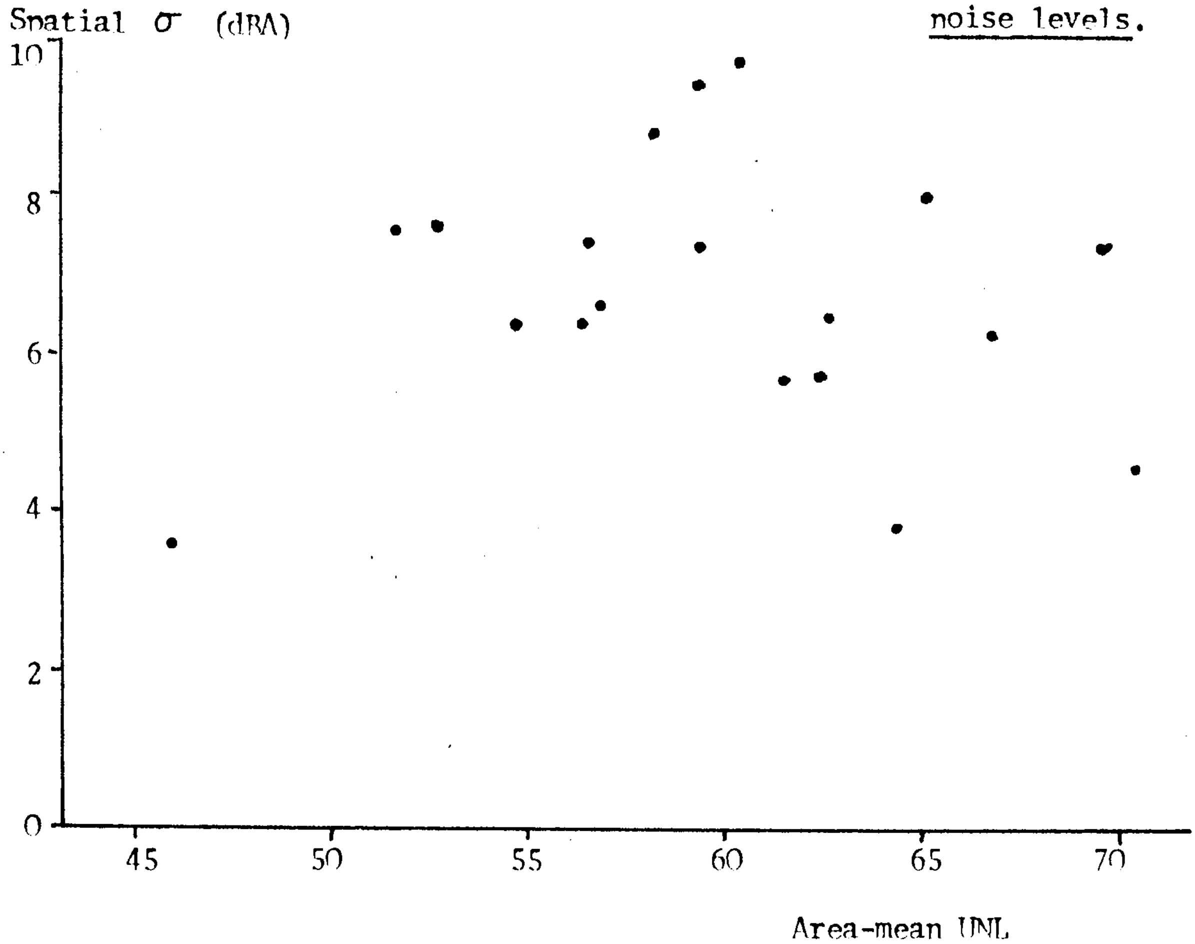
I " " " industry

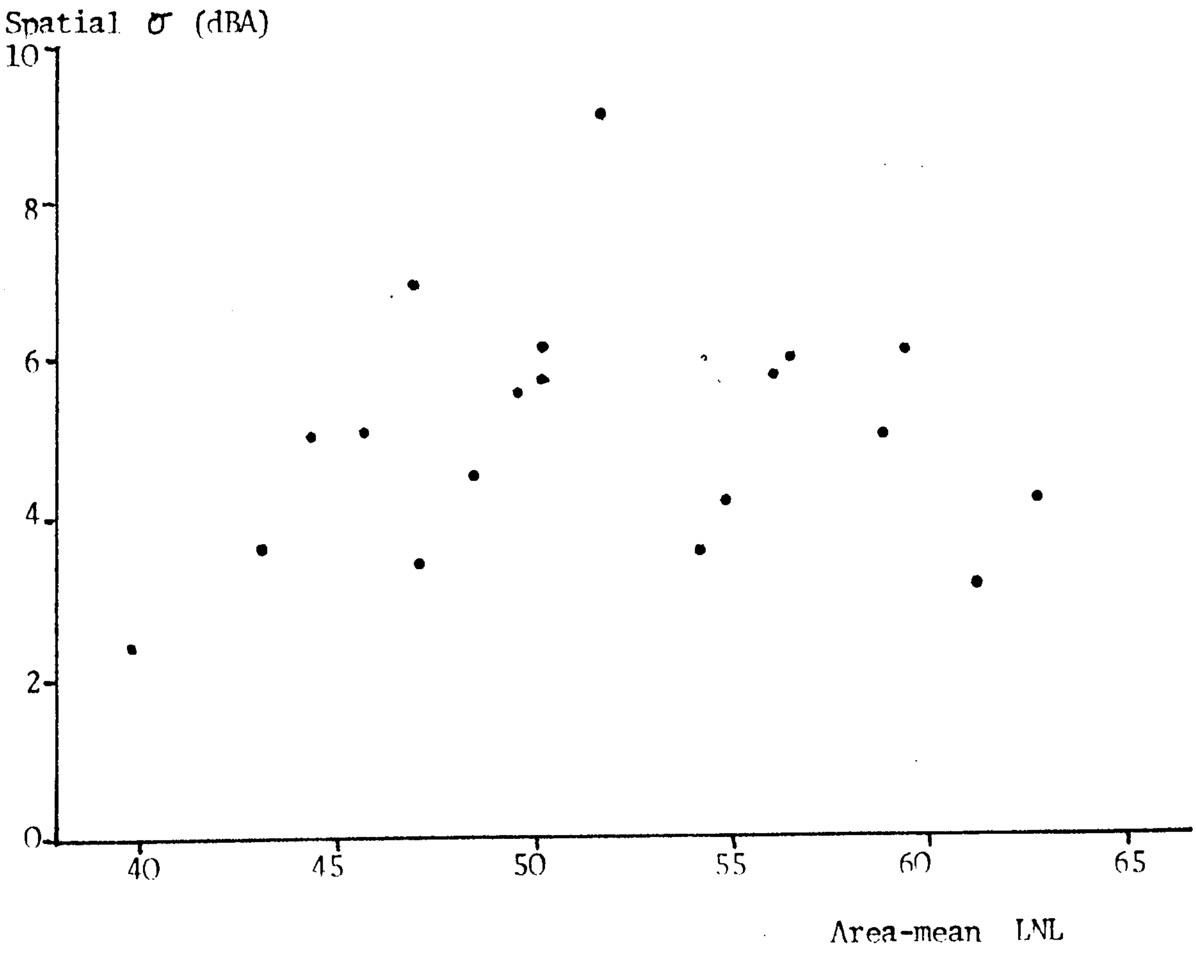
B Back gardens surrounded by houses

prediction model from a method for predicting TAE area-means to one for predicting the means of individual sites based on a quite simple classification of the type of site. As an indication of the increased accuracy to be gained, the case study showed that the variations in noise levels within each site-identity category were such that a prediction accuracy of some ± 4dBA and ± 3dBA could be attained for UNL and LNL respectively. The results should be viewed with caution however because of the small samples involved.

Table 5.6 showed the standard deviations of the within-TAE spatial variation in noise levels, and from the table it is evident that these are considerable variations in the standard deviations observed in different TAE types. An assessment of the degree of the difference between the spatial variation in noise levels in different types of areas has been recommended by SAFEER (1973), as a means of determining whether different types of area require different sampling densities if a consistent accuracy in the resulting area-means is to be achieved. The results of this research allowed the issue to be pursued in some detail. Figs. 5.6(a) and (b) show plots of the standard deviations of the spatial variation of the TAE types given in Table 5.6 against their observed UNL and LNL area-means. The data are indicative of a general trend whereby the most spatially homogeneous area types are those where the mean noise levels are either very high or very low, and the most variable types are those with fairly average area-means; this trend is also more apparent for LNL than for UNL. This is intuitively reasonable since where there is a general prevalence of either very noisy or very quiet conditions (for example in commercial centres, TAE type 2A, and countryside, TAE type 3C, respectively) the spatial variability will be low, while areas with intermediate area-means encompass a mix of noisy and quiet conditions (for example the TAE type 5C, where small commercial centres are found

Fig. 5.6 Within-TAE spatial variation plotted against area-mean noise levels.





within outer suburban residential areas) will exhibit a high spatial variability. This type of relationship is not evident in the case of temporal variability. Table 5.7 shows the within-day temporal errors of estimate in the area-mean for each TAE type; note that the pooled values were used to achieve the element $C_{1,0}$ in Table 5.3.[1] These values are plotted against their relevant area-mean values in Figs. 5.7(a) and (b), and it is seen that there is no evidence of a relationship.

From the data presented in the figures therefore, it may be concluded that the sampling density of TAEs with middle-range area-means should be higher than that for the noisiest and quietest TAEs if it is desired to attain consistent sampling errors from the whole range of TAEs. More extensive research is required however before such a relationship can be quantified sufficiently for a numerical difference in sampling densities to be recommended, and in any case the effect appears to be quite marginal especially in the case of UNL. No particular generalisation may be made in respect of the sampling time; it is of interest however to note that a relationship appears to hold between the short-term statistical variability of areas and their within-TAE spatial variability. The short-term variability at a given site was measured by an 'instability factor' I, this being a factor of the difference between the observed values of UNL and LNL,[2] from which a pooled value of I was obtained for each sample

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1. $C_{1,0}$ is examined here rather than the normalised between-day variation $C_{2,0}$ since sampling is carried out within a single day and so it is the (within-day) sample time that is of interest.

2. Since UNL and LNL have been taken as equivalent to the L_{10} and L_{90} of the short-term sample distribution, the standard deviation σ of this distribution may be estimated (assuming normality) from the fact that (UNL - LNL) $\simeq 2 \times 1.96\sigma$. Since normality has not been proven, σ is simply an indicator of the temporal variability within the sample period, and here is termed the 'instability factor' I.

Table 5.7 TAE Matrix Giving Standard Within-Day Temporal Errors of Estimate for the Area-Mean Values of UNL and LNL (dBA)

LAND USE	NETWORK DENSITY A, Dense	B. Medium	C. Sparse
0. Residential	1.94 0.94	1.43 0.99	1.62 0.64
1. Industrial	0.93 0.64	1.01 0.73	*
2. Commercial	0.76 0.51	*	*
3. Open Space	*	*	1.58 0.88
4. Res/Ind	2.21 1.27	0.91 0.62	*
5. Res/Comm	0.77 0.34	1.50 0.46	1.13 0.87
6. Ind/Comm	1.35 0.69	1.54 1.04	*
7. Res/O. S.	1.24 0.73	0.94 0.61	1.45 0.94
8. Ind/O.S.	*	0.57 0.56	1.29 1.25

Cell Code: Upper figure: UNL Standard Deviation

Lower figure: LNL Standard Deviation

* : Insignificant proportion (less than 0.5%) of the WMMC are in the category.

N.B. Data normalised for windspeed

Fig 5.7 Observed within-day temporal variation plotted against area-mean noise level.

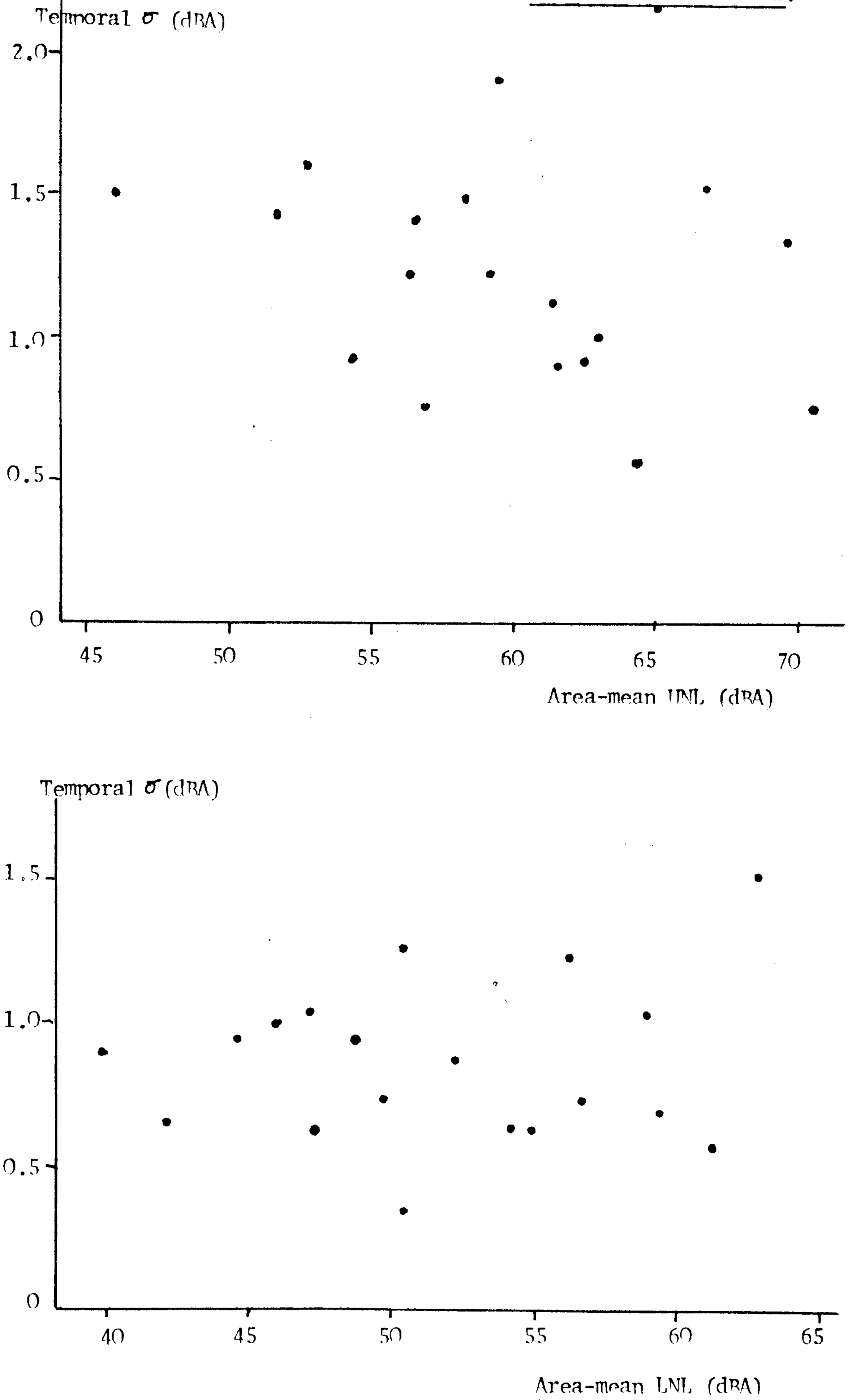
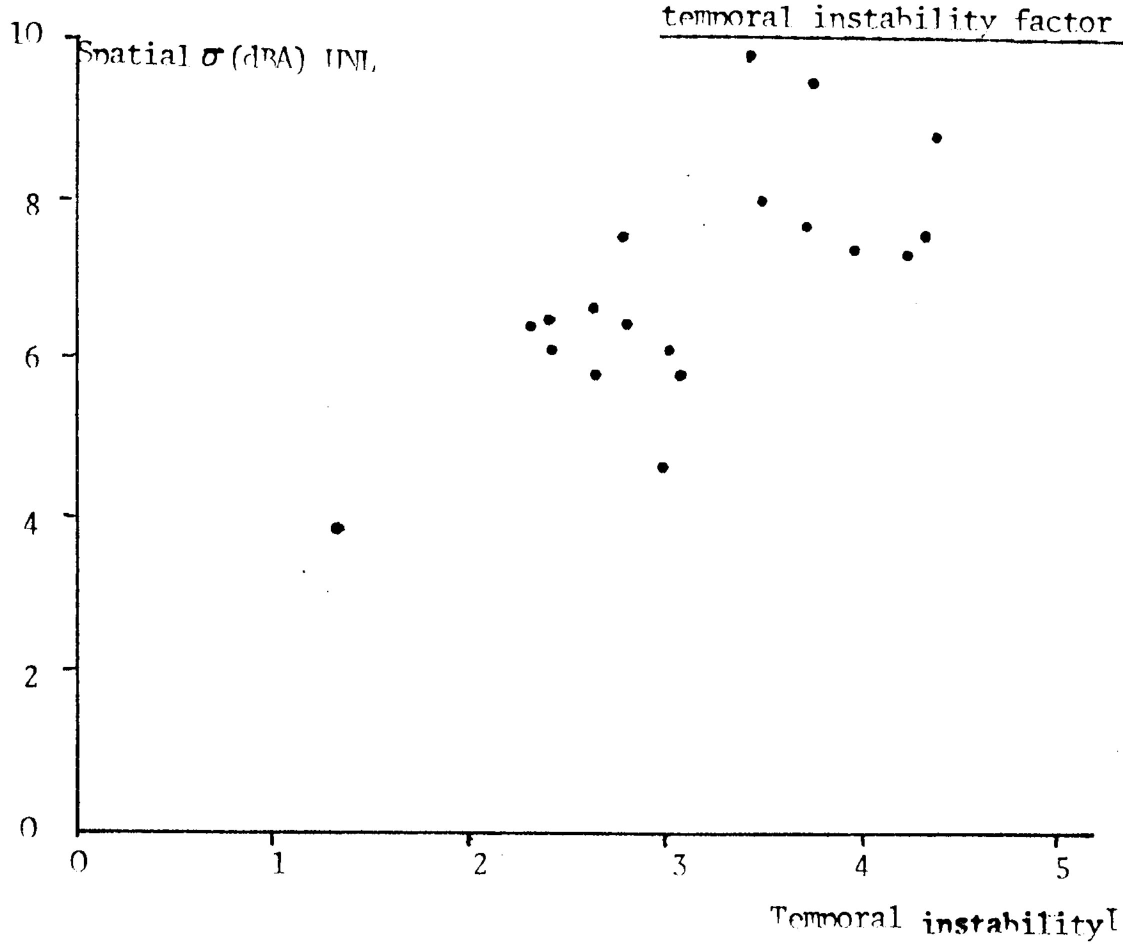
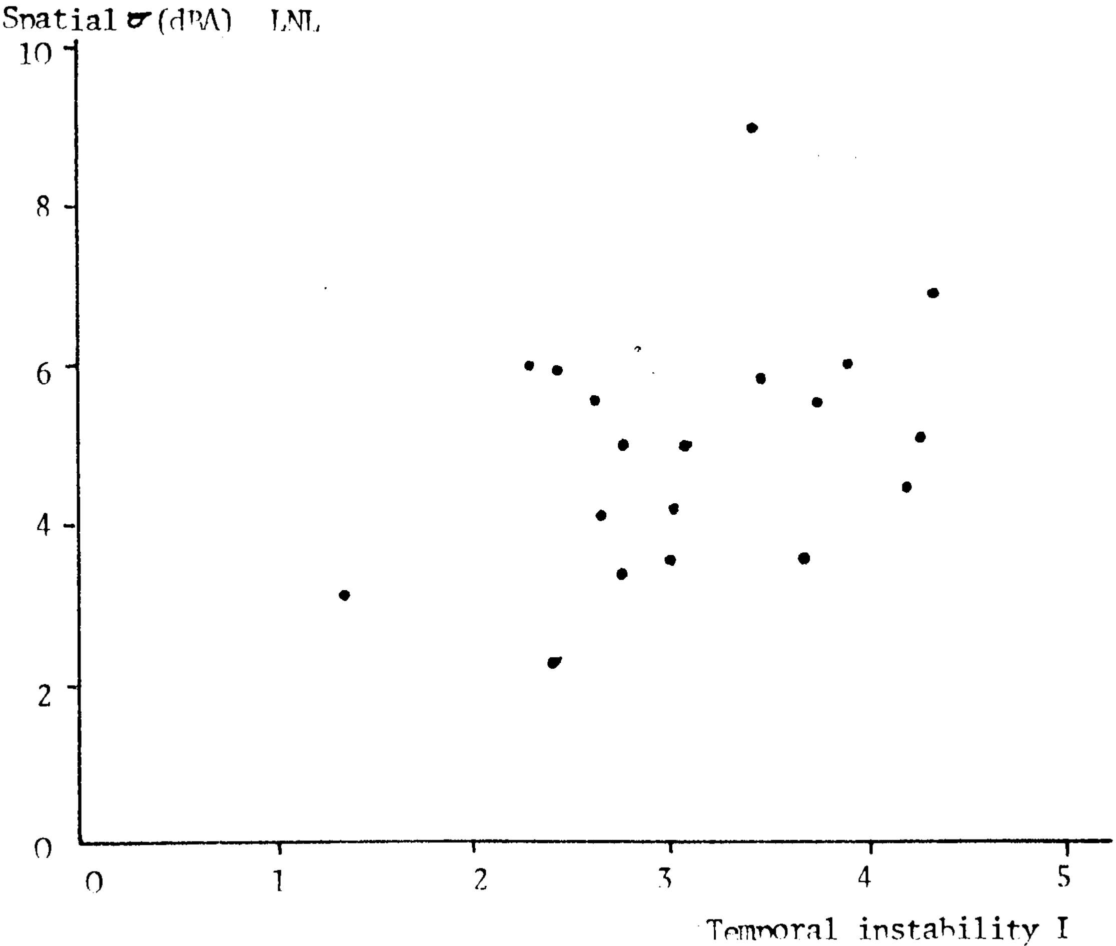


Fig 5.8 Within-TAF spatial variation plotted against short-term temporal instability factor I.





TAE. Figs. 5.8(a) and (b) show the standard deviation of the within-TAE spatial variations (Table 5.6) plotted against the values of I; a linear relationship between the two parameters is indicated, especially in the case of UNL. There appears to be no immediately obvious reason for this in terms either of area types or area-mean noise levels.

This section has discussed theoretical and empirical issues and results that have a less immediate bearing upon the research problem than the three key objectives outlined in the introduction of the chapter. The results do however contribute to the general research area of ambient noise studies; moreover in the case of the windspeed-noise model the work was essential to allow the testing and calibration objectives to be pursued, and the study of spatial and temporal variances may lead to further research in the development of more efficient survey and sampling techniques.

5.5 APPLICATION OF THE TAE PREDICTION MODEL AS A MAPPING METHOD

This section describes the way in which the third of the key objectives for testing the TAE mapping methodology was pursued. This objective involves the application of the TAE prediction model as a mapping methodology. As stated in Chapter 3.4, the choropleth cartographical method necessitates the use of only a small number of different categories in the display of data, and it was seen that five categories, consisting of groups of TAE types, were chosen as the basis of the TAE mapping method. This section describes the grouping method through which the five categories were achieved, and presents and discusses the resulting ambient noise maps.

5.5.1 Grouping the TAE Types and Mapping the Data

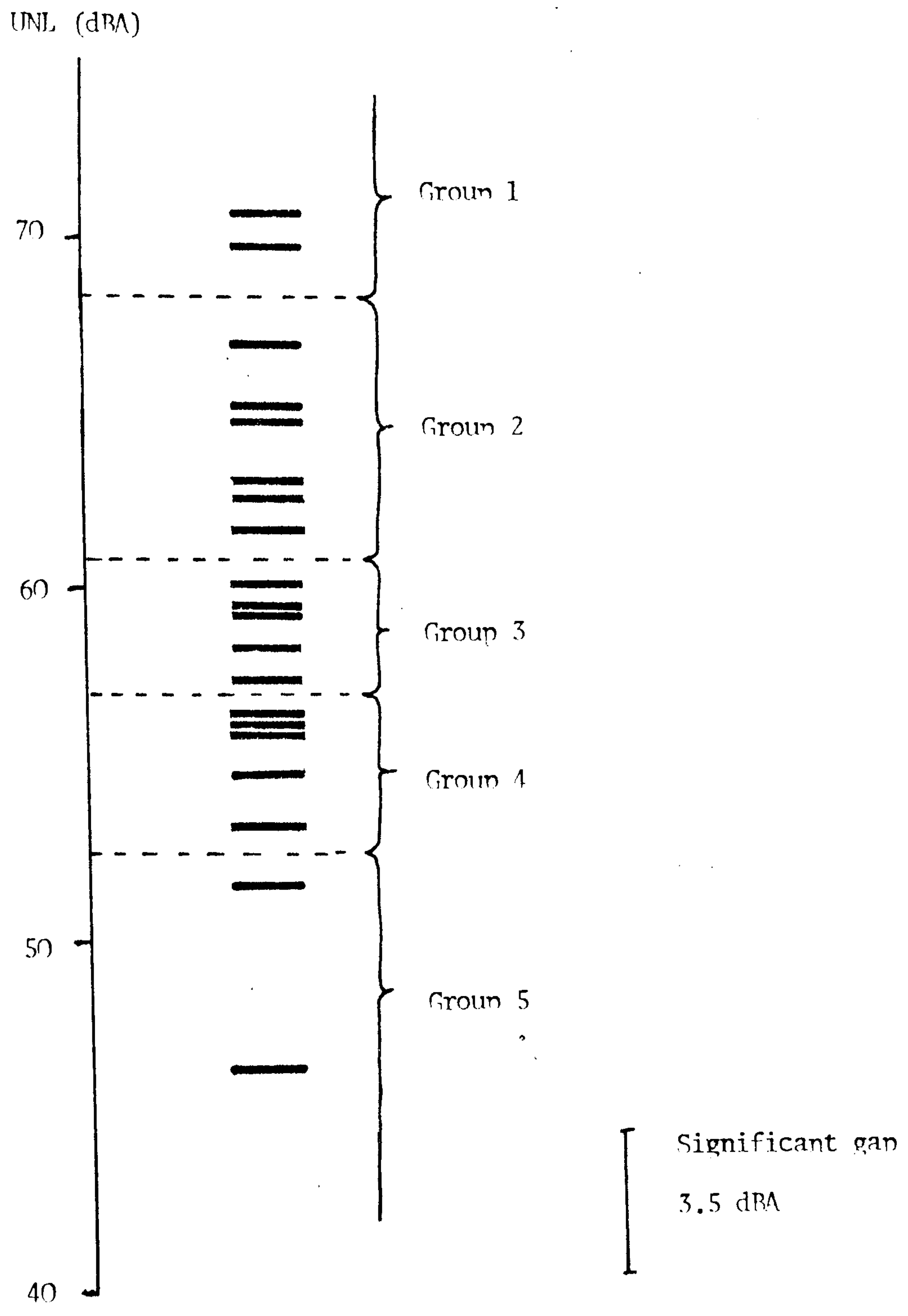
In addition to simplifying the cartographic display, the need to group TAE types used in the prediction model was also seen to be connected with the 'metric' accuracy of the measurements or predictions of the conditions of zones. This issue has already been raised in section 5.2 in connection with the uses of the TAE prediction model. It is particularly important in the application of the TAE prediction model as a mapping method, for although the statistical analysis of variance test has shown that the conditions found within the different TAE types do not all come from the same population, this test does not show that each TAE type is statistically significantly different from all the others. In fact, as Fig. 5.9 illustrates, it is evident that many TAE types are not significantly different from each other[1], the 'significant gaps' being 4.1 dBA and 3.5 dBA for UNL and LNL respectively. Consequently the TAE prediction model could not be used directly as a method for predicting the conditions of areas each with statistically unique conditions of noise; as seen below, it was necessary to group TAEs so that each group covered an interval at least as large as the 'significant gap'.

Chapter 3 gave five possible methods of grouping and without specifying the exclusive use of any particular method it was stated that the 'natural grouping' technique was generally the most appropriate because it minimised the loss of 'metric' information consequent upon grouping. EDWARDS (1964) presents a three-stage statistical procedure due to TUKEY (1949) in which 'natural grouping' may be conducted on the basis of the variations in the data involved.[2] This procedure is analytically complicated however, and moreover in this research context it was necessary to consider not just the nature of the data but also the nature of the urban fabric;

1. The test for a 'significant gap' is derived from the standard error of the difference between the area-means of a given TAE type, using the students 't-test' at 95% confidence.

2. Given a set or order of sample means, the method allows the researcher to "Section this ordering in such away that we could say the means falling within a given section are alike in that they do not differ significantly among themselves, but that these are significant differences between sections"(EDWARDS, 1964).

Fig. 5.9 Distribution of predicted TAE type area-mean UNL noise levels, related to statistically significant 'gaps'.



for in accordance with the principles of the TAE methodology it is necessary to preserve as much characteristic urban fabric identity as possible within the groupings.

The introduction of other than purely statistical criteria does not affect the theoretical validity of grouping, since grouping is often used as a quite arbitrary means of aggregating data, as Dickinson's list of methods given in Chapter 3.4.1 shows. For example if it had been feasible to sample the noise levels in all 575 TAEs in the WMMC it would still have been necessary to group the range of observed levels into the five categories, and an arbitrary arithmetical method, such as the 'equal interval' approach (e.g. intervals at 45 dBA, 50 dBA, 55 dBA etc.), would have been necessary if the range of observed TAE noise levels had formed a continuous distribution without evident 'natural' breaks. Clearly the above example is susceptible to a 'grouping error' which is proportional to the measurement and sampling errors; for example a TAE with a 'true' population mean noise level of 49 dBA may record an observed sample mean of 51 dBA and therefore be incorrectly allocated to the 50-55 dBA group. The grouping of TAE types is beset by precisely the same problem, except that it involves a prediction error rather than a measurement error. Naturally as the groups interval is widened to a margin in excess of the prediction error, the chances of incurring a grouping error decrease; at the same time however the metric information carried by the resulting groups decreases, and so it is necessary to keep the group intervals to an optimum size which is just wide enough to hold grouping error at a tolerable level. As a criterion for this it was decided that in all the case studies, group intervals should not be smaller than the 95% confidence level for a significant 'gap', i.e. in this case 4.1 dBA. The grouping method itself is described below, and it will be seen (e.g. Table 5.9) that the group interval criterion was achieved. As a simple test of the extent of

Table 5.8 Grouping of TAE Types: Predicted Noise Levels and Ranks

Group	TAE Type	Predicted Values (dBA)			Predicted Rank			% of WMMC area in group
		UNL	LNL	L_{eq}^{*}	UNL	LNL	L_{eq}	
1	2A Commercial/Dense	70.6	62.7	67.7	1	1	1	2.0
	6A Ind/Comm/Dense	69.7	59.5	66.2	2	4	2	
2	6B Ind/Comm/Medium	66.8	60.1	64.2	3	3	3	16.1
	4A Res/Ind/Dense	65.1	56.1	61.9	4	6	5	
	8B Ind/O.S./Medium	64.7	61.8	63.3	5	2	4	
	1B Industrial/Medium	63.1	56.6	60.6	6	5	6	
	1A Industrial/Dense	62.6	54.1	59.4	7	8	8	
	4B Res/Ind/Medium	61.8	54.9	60.4	8	7	7	
3	5C Res/Comm/Sparse	60.2	51.9	57.1	9	9	9	16.5
	0A Residential/Dense	59.6	48.6	58.8	10	13	11	
	7A Res/O.S./Dense.	59.4	49.6	56.1	11	12	10	
	5B Res/Comm/Medium	58.4	47.5	54.9	12	14	12	
	5A Res/Comm/Dense	57.4	50.4	54.7	13	10	13	
4	0B Residential/Medium	56.5	45.7	53.0	14	16	15	31.1
	8C Ind/O.S./Sparse	56.3	50.3	53.9	15	11	14	
	7B Res/O.S./Medium	54.7	47.2	51.8	16	15	16	
	0C Residential/Sparse	53.3	43.1	49.6	17	18	17	
5	7C Res/O.S./Sparse	51.6	44.4	48.8	18	17	18	34.3
	3C Open Space/Sparse	46.3	39.7	43.7	19	19	19	

* Estimated values of L_{eq}

the eventual grouping error, it may be noted that of the eleven TAEs observed in the Phase 2 survey, ten were found to lie within the same group interval as that to which they had been allocated by the 'grouped' TAE prediction model.

As stated, grouping was undertaken through joint consideration of natural metric 'breaks' (assessed visually) and discontinuities in the urban fabric characteristics of the TAE types. The assessment of metric 'breaks' was complicated by the fact that two measurement scales - UNL and LNL - were available. Priority was given to the UNL scale since the UNL values are numerically more akin to the estimated L_{eq}, this being the nearest to a single 'representative' statistical indicator.[1] Table 5.8 shows the slight natural 'breaks' which occur in the UNL values between

Table 5.9 Summary of Noise Level Indicator Intervals in the Five Groups

GROUP	NOISE LEVEL INTERVALS PER GROUP (dBA)			% of WMMC area in group
	UNL	LNL	L_{eq}	
1	Over 68	Over 61	Over 65	2.0
2	61-68	54-61	58-65	16.1
3	57-61	50-54	54-58	16.5
4	52-57	44-50	49-54	31.1
5	less than 52	less than 44	less than 49	34.3

types 6A and 6B, 4B and 5C, 7A and OB, and 7B and 7C, (these are also evident in Fig. 5.9), and illustrates the fact that while the estimated

1. It was not considered advisable to perform the grouping on the estimated L_{eq} scale directly, owing to the additional (and unquantified) error of estimation in the data.

L_{eq} scale shows a reshuffling of types within these groups, this does not cause TAE types to be transported from one group to another. A similar effect is seen in the case of LNL, although some TAE types do show between-group reshuffling (for example, types 6A and 1B). The urban fabric constitution of these groups is discussed in section 5.5.2 following. The metric intervals for the groups in terms of UNL, LNL and the estimated L_{eq} are summarised in Table 5.9 which shows that the requirement for group 'intervals' to exceed the significant gap is satisfied; this table therefore defines the ambient noise characteristics of the five groups of area type which are represented in the mapping exercise.

Table 5.8 is essentially a reformulation of the TAE prediction model shown in Table 5.2, and from it the TAE methodology was implemented as a mapping method. The urban fabric data for the WMMC study area, mapped in the form of TAEs as described in Appendix A, were taken and each TAE was allocated into the appropriate one of the five groups of noise conditions according to the 'calibrations' prescribed by Table 5.8. This resulted in a map of predicted ambient noise conditions over the WMMC expressed in terms of five groups of noise conditions, as illustrated in Fig. 5.10. The map is overlaid by a transparancy of the map in Fig. 4.4 which shows the pattern of the principal land use activities within the WMMC; the spatial association between the predicted ambient noise pattern and the land use activity pattern will be noticed.

For some planning purposes it is necessary to give particular emphasis in the display to the more severe environmental conditions. This is achieved in Fig. 5.11 which shows only group 2 ('stress') areas and group 1 ('high stress') areas. The definition of 'stress' and 'high stress' areas is in general somewhat arbitrary although a quantitiative basis is given by the facts that (a) the lower limit to 'stress' area UNLs (62 dBA)

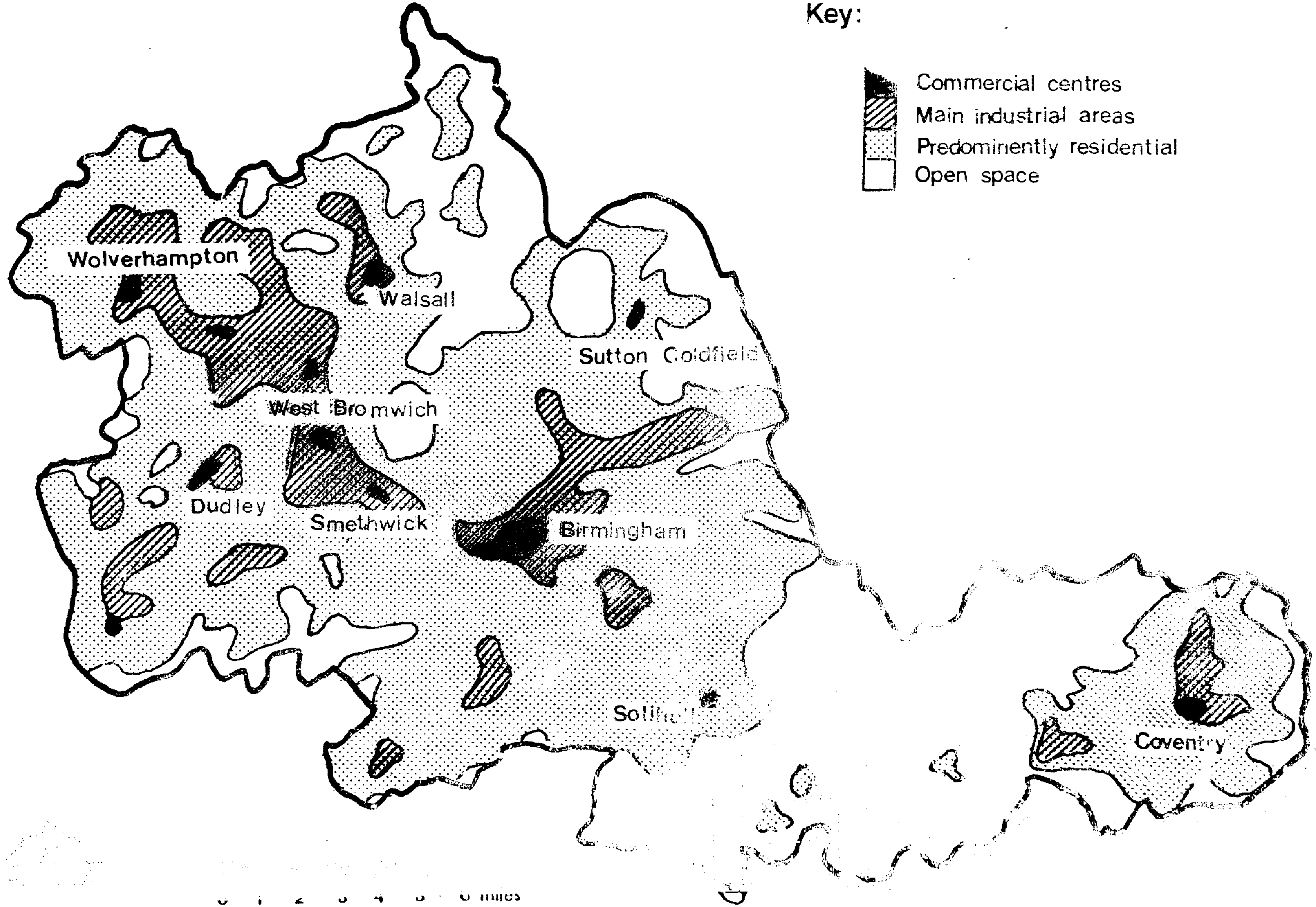


Fig. 5.10 Map showing predicted ambient noise conditions in the WMC.

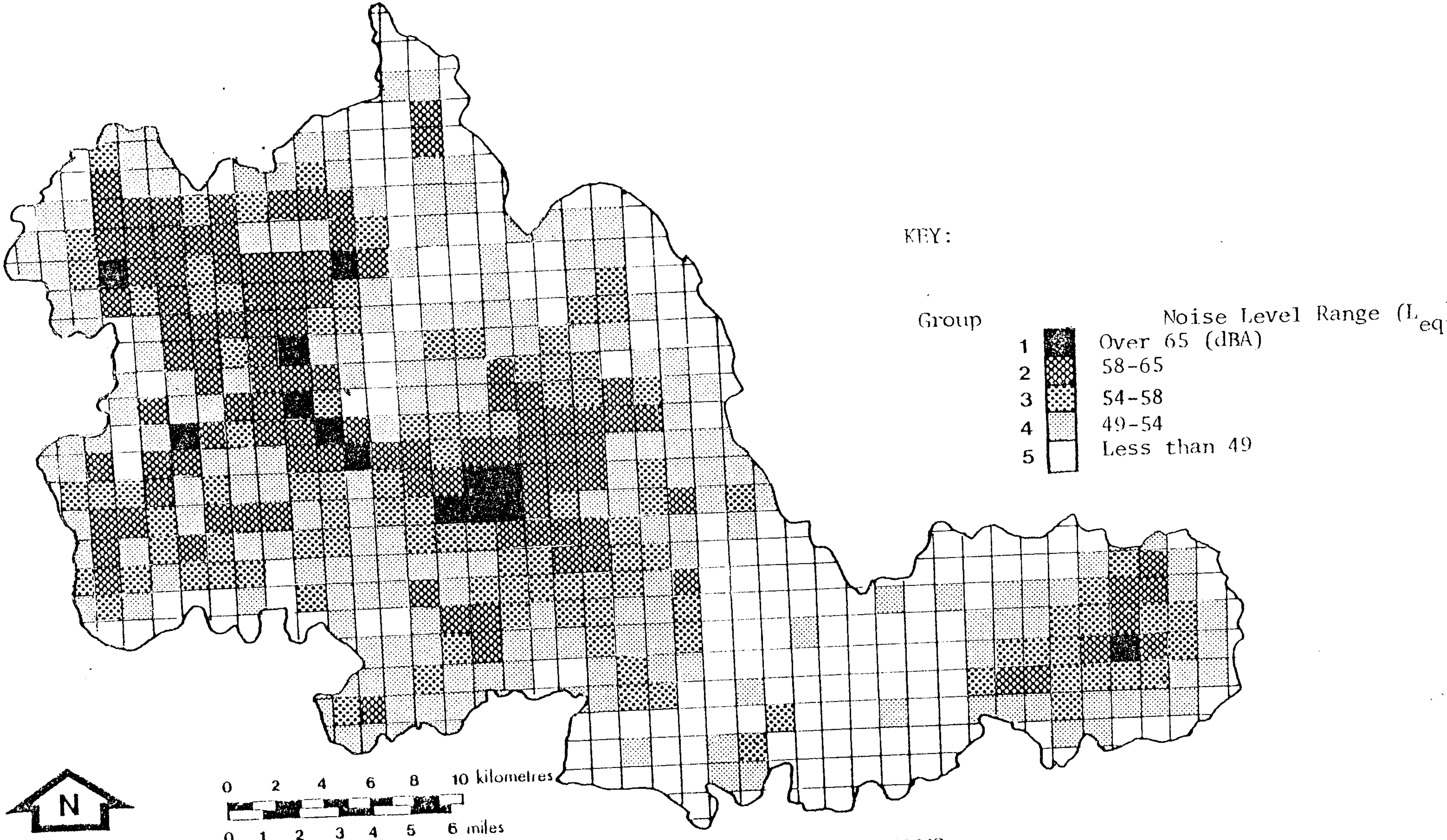


Fig. 5.10 Map showing predicted ambient noise conditions in the WMMC.

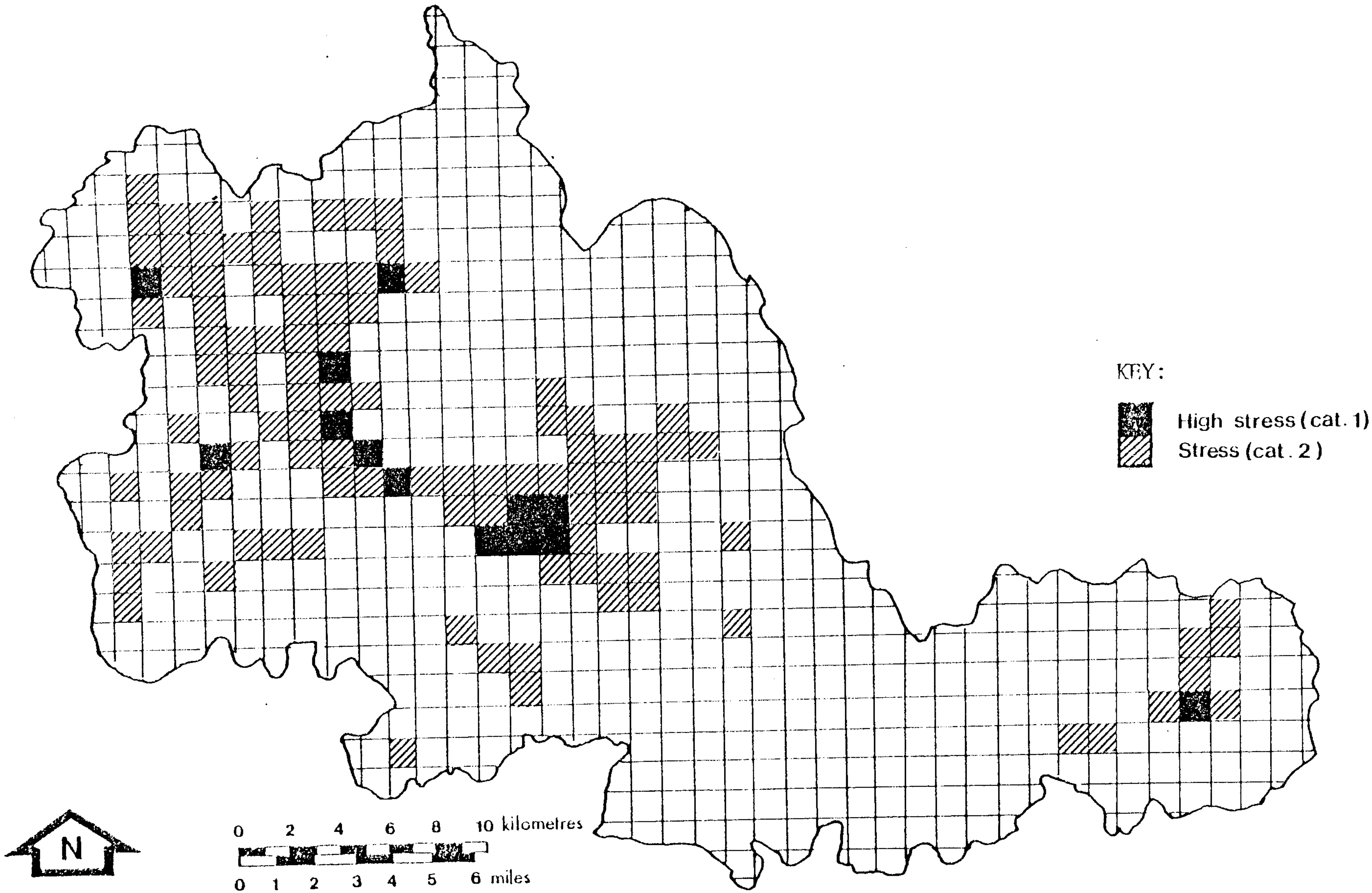


Fig. 5.11 Map showing location of 'stress' and 'high stress' areas in the WMMC

is approximately the level at which noise begins to interfere with speech,[1] and (b) the lower limit to the 'high stress' area UNLs (68 dBA) is equivalent to the (18-hour L_{10}) level at which residents may receive compensation under the Land Compensation Act 1973.

5.5.2 Discussion of the Results

Table 5.8 indicates the urban fabric consistency of the five mapped groups. Group 1, the noisiest, contains the principal commercial and industrial centres while group 2 covers almost all the industrial areas and those mixed with residential or commercial uses where the road network is dense or of medium density. Group 3 is predominantly residential with small shopping centres and medium to dense network density while group 4 includes residential areas, commonly in the outer suburbs, which are mixed with open space or have a sparse road network; in addition this group includes areas with industrial uses mixed with open space and served by a sparse road network - such areas are commonly warehousing, sewage works or mining areas on the urban periphery. Group 5 represents the quietest areas with little urbanisation, for example open or agricultural countryside, parkland, rural settlements, and residential areas mixed with open space on the urban-rural fringe.

When mapped through the 'grouped' TAE methodology as shown in Figs. 5.10 and 5.11, the pattern of these five groups is more graphically illustrated. The large commercial and industrial centres (Birmingham, Coventry, Walsall, Wolverhampton, West Bromwich and Dudley) are clearly identified, together with the broad belt of group 2 areas where industry predominates in the Black Country and to the North and East of Birmingham.

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1. A study by the EPA (1971) has shown that interference with speech is commonly noticed when noise levels reach 60-65 dBA.

To the South and West of Birmingham the quieter residential groups 3 and 4 are to be found, while the 'green belt' land between Walsall and Birmingham together with the countryside surrounding the conurbation and the large farm land area in the Solihull District separating Birmingham and Coventry are clearly evident as group 5 areas.

During the survey the most prominent noise source at each observation site was noted and Table 5.10 represents a summary of this data for each

Table 5.10 Frequency of Most Prominent Noise Sources in the Five Groups

Most Predominant Noise Source Type	TAE Group Numbers				
	1	2	3	4	5
Road traffic	77.5	56.5	81.0	59.0	55.0
Residential noise and children	2.5	2.5	9.0	11.0	10.0
Industry	15.0	39.0	2.0	22.5	0.0
Aircraft	0.0	0.0	1.0	0.0	5.0
Railways	0.0	0.0	1.0	0.0	7.5
Construction Sites	5.0	1.5	2.0	0.0	0.0
Natural (e.g. birds, wind)	0.0	0.0	4.0	7.5	22.5

of the five groups, showing seven categories of source. It is seen that in every group road traffic is the most prominent source of noise, although it is predictably more prevalent in the groups which incorporate dense-network TAE types. The only other source which occurs with any great frequency is industry. This is naturally most prominent in the industry-dominated group 2; the high frequency also encountered in group 4 may be explained by the prominence of warehousing and mining activities on the periphery of the West Midlands Conurbation. The strong influence of natural noises in the predominantly rural group 5 is also noteworthy. In

Section 5.6 these results are compared with those of other UK surveys.

This section has examined the third key objective, that of grouping and mapping the ambient noise conditions predicted by the TAE prediction model. The maps have illustrated the value of a method that allows ambient noise and the urban fabric to be related in a prediction model. Through the maps it is argued that the TAE methodology can provide both the 'baseline' and the 'dynamic' (i.e. prediction) information to aid such policy contexts as strategic level Environmental Impact Analysis, development control, transport planning, development planning, etc., as listed in general terms in Chapter 1.1.

Both maps should be compared with the map in Fig. 4.4 which shows the pattern of the principal land use activities within the WMMC; the spatial association between the predicted ambient noise pattern and the land use activity pattern will be noticed. The accuracy of the Table 5.8 'prediction model' for groups of areas cannot be statistically assessed independently of the data used to determine the accuracy of the TAE prediction model of Table 5.2. However it may be noted that of the eleven TAE units observed in the survey Phase 2, ten fell into the correct noise group as predicted by the 'calibration' expressed in Table 5.8.

5.6 COMPARISONS AND CONCLUSIONS

This section completes the empirical case study for ambient noise by comparing the results and method with those of other contemporary studies, and making conclusions about the strengths and weaknesses of the TAE mapping method; proposals for further research are also made.

5.6.1 Comparison of Results with other Studies

The task of comparing the results of this study with those of other studies is complicated by the differences in area classification. The only classification which has any status as a 'standard' is that given in BS4142. Comparisons are therefore made in two stages, considering firstly the noise levels observed in various different classifications of area, and secondly those observed in the BS4142 categories.

Table 5.11 shows the results of this research compared with those for three other classifications: the 'notional' background (L_{90}) levels as given in BS4142 (BSI 1975), the L_{10} and L_{90} levels for four types of area in Vancouver (PRICE 1972) and the L_{50} values for various categories of area in Tokyo (TOKYO METROPOLITAN GOVERNMENT 1977). Notwithstanding the limits of quantitative comparison imposed by the differences in indicator type and area classification, it is possible to conclude that commercial areas are generally the noisiest; that the general ordering of area types with respect to noise is consistently commercial, industrial, residential, rural; and that the general levels in each case are comparable wherever meaningful comparisons are possible.

Comparisons between noise levels observed within the 'standard' BS4142 categories are somewhat more meaningful, although the fact that this classification is not comprehensive with respect to area types (for example there is no commercial category or reference to open space) means that spatially comprehensive surveys must use judgement and approximation in the classification of some sites, and consequently the composition of the data within each category does not always correspond precisely to the category heading. Table 5.12 shows the comparison between the BS4142 'notional' levels (L_{90}) and those observed in three UK surveys. That of ATTENBOROUGH et al (1976) involved sites selected at random across the UK; GILFORD and NORRIS (1973) observed levels located at grid-nodes within the WMMC. The data from this research is that obtained from the

Table 5.11 Comparison of Noise Levels in Various Categories of Area from Four Studies

POCOCK (West Midlands) Category	$L_{10}^{*}L_{90}^{*}L_{eq}^{*}$	BS 4142 (UK)** Category	L_{90}	PRICE (VANCOUVER) Category	L_{10} L_{90}	TOKYO METROPOLITAN GOV'T Category	L_{50}
Commercial	A 71,63,68	Predominantly industrial	75	Commercial	72,51	Commercial	66
Comm/Ind	A 70,60,66	Res/Ind mix	70	Industrial	69,49	Quasi-commercial	65
" "	B 67,60,64	Predominantly residential, some industry	65	Residential	64,42	Exclusively industrial	64
Industrial	A 65,56,62	Urban (Residential)	60	Rural	58,36	Quasi-industrial	61
Res/Ind	A 65,62,63	Suburban (little road traffic)	50			Industrial	60
Ind/O.S.	B 63,57,61	Rural (Residential)	50			Residential	58
Industrial	B 63,54,59					Residential (ClassB)	54
Res/Ind	B 62,55,60					Residential (ClassA)	51
Res/Comm	C 60,52,57						
Residential	A 60,49,56						
Res/O.S.	A 59,50,56						
Res/Comm	B 58,48,55						
" "	A 57,50,55						
Residential	B 56,46,53						
Ind/O.S.	C 56,50,54						
Res/O.S.	B 54,47,52						
Residential	C 53,43,50						
Res/O.S.	C 52,44,49						
Open Space	C 46,40,44						

* Estimated indicator values

** Notional levels (no published survey data)

Table 5.12 Comparison of the Notional Noise Levels (L_{90}) in BS 4142 Categories with Results from Three UK Surveys

BS 4142 Category	BS 4142 (Notional)	ATTENBOROUGH et al*	GILFORD and NORRIS	POCOCK
Rural (residential)	50	44.4	43	44.8
Suburban (little road traffic)	55	46.7	42	47.5
Urban (Residential)	60	52.0	47	52.2
Residential (some industry)	65	54.1	50	56.1
Intermediate industrial and residential	70	56.6	57	57.7
Predominantly industry	75	57.0	52	57.4

* Includes addition of 0.3 dBA to give 'working day' mean

Phase 1 survey, reclassified into BS 4142 categories.[1] The three surveys show a remarkable degree of similarity in the observed levels; this is particularly evident in the association between the results of this research and those of ATTENBOROUGH et al (1976). The surveys are also consistent in their disparity with respect to the 'notional' levels of BS 4142, and this finding must cast considerable doubt upon the validity of these notional levels.

Mention was made in section 5.5.2 of the investigation of the most prominent noise sources at each site, and the aggregate results of this study are compared in Table 5.13 with the results of the two other UK surveys. Once again a considerable consistency in the results is evident,

1. Each of the five 'locations' in every TAE was allocated an appropriate BS 4142 category on the basis of the observed nature of the location.

particularly in respect of the dominance of road traffic.

Table 5.13 Frequency of Most Prominent Noise Sources in Three UK Ambient Noise Surveys

Source type \ Survey	POCOCK (Weighted County Aggregate)	WMNS (GILFORD and NORRIS)	National Survey (ATTENBOROUGH et al)
Road traffic	61.5	61.9	63.7
Residential noise and children	8.9	9.4*	19.0*
Industry	13.8	15.2	12.4
Aircraft	1.9	0.8	4.1
Railways	2.7	3.4	0.8
Construction Sites	0.5	5.1	0.0**
Natural (e.g. birds, wind)	10.7	4.2	0.00**

* includes other miscellaneous sources ** not included as a separate category

5.6.2 Summary, Comparisons and Conclusions in Relation to the TAE Mapping Methodology

This Chapter has described the way in which an empirical case study of the WMMC was conducted to test the TAE mapping methodology for urban ambient noise. Three objectives were pursued; (i) the testing of the 'TAE Hypothesis', (ii) the calibration of the TAE prediction model, and (iii) the application of the model as a mapping method. The Chapter now concludes with a summary and appraisal in relation to these objectives; in each case the main conclusions are summarised, the key points of the empirical methods are given, and comparisons are made with other equivalent studies. It should be noted that conclusions which have a bearing upon the more general objectives of the research as summarised in Chapter 1.5, are included in Chapter 9.

(a) The test of the TAE hypothesis

(i) An 'analysis of variance' F-test was performed upon data sampled from examples of each TAE type, under the null hypothesis that no significant difference existed between the noise levels of the TAE types. F-values of 14.8 and 28.7 were obtained for the UNL and LNL indicators respectively, indicating that the null hypothesis should be rejected at well above the 99% confidence level. Consequently it was concluded that the TAE hypothesis was valid.

(ii) A theoretically valid test of the hypothesis could not be achieved until the test data had been corrected for biases arising out of the sampling procedure. Firstly the data had to be normalised to a 'light wind' condition in order to eliminate the effects of wind-speed on the observed ambient noise levels. Secondly the measures of variance upon which the F-test depends had to be corrected by adding and subtracting various appropriate component elements of variance. In order to achieve this it was therefore necessary for a 'Windspeed-Noise' model to be developed to facilitate the normalisation, and for an explicit appraisal of all the components of sampling (error) variance encountered in the empirical method to be made.

(iii) The Windspeed-Noise model was developed empirically on the basis of observed differences in noise level and simultaneously - observed differences in windspeed; possible theoretical (causal) factors were also discussed. The model predicts the increase in a given ambient noise level caused by a given windspeed expressed in the Beaufort Scale. Using the empirical model it was shown that over 90% of the variance between area-mean noise levels observed on different days could be explained by the effects of windspeed variations.

(iv) The temporal and spatial components of the sampling errors were assessed through an analysis of all three survey phases, and the results were expressed in the form of a matrix. In addition to providing the data for the correction of the F-ratio (and assessing the accuracy of the TAE prediction model and providing further valuable knowledge - see later), the matrix showed that the sampling period and sampling density were mutually compatible in that the temporal and spatial sources of sampling error were of roughly equal proportion.

(v) The urban fabric classification used to define TAE types is more typologically detailed and comprehensive than the classifications of other equivalent studies; the nineteen TAE types should be compared with the nine categories used by the TOKYO METROPOLITAN GOVERNMENT (1977), six by the BRITISH STANDARDS INSTITUTION (1977, 1975), ATTENBOROUGH et al (1976), and GILFORD and NORRIS (1973), and four by PRICE (1972). To the author's knowledge the specific inclusion of a 'road network density' parameter in the area taxonomy is original, although it follows the recommendations of other workers (ATTENBOROUGH et al 1976, GILFORD and NORRIS 1973, ELDRED 1975), and the studies by WOOD et al (1974) and SOUTH YORKSHIRE COUNTY COUNCIL (1978a) both adopt simple, general parameters of traffic density. The TAE matrix has shown that the two parameters, land use and road network density, explain the total variance of ambient noise across the study area in a ratio of approximately 3:2. To preserve consistency therefore it is recommended that the number of network density categories be increased relative to the number of land use categories so that the ratio of categories reflects the ratio of explained variance. The 'road network density' paramater was measured and categorised on a somewhat arbitrary basis (see Appendix A), and it is recommended that future studies should develop a more quantitive system (for example using 'vehicle-Km per TAE').

(vi) The use of the F-test to examine the validity of the classification system represents a more rigourous approach than is common in most ambient noise studies, although the F-test was also used in testing the 'category' prediction model of ATTENBOROUGH et al (1976).

(vii) By investigating the ambient noise conditions of a limited number of types of area, the TAE hypothesis allows characteristics of the noise climate of areas to be classified by area type. Thus it has been possible to examine the relationship between the general spatial variability of noise levels within a given area and the area type, a study recommended by SAFEER (1973). The results indicate that the noisiest and quietest areas show least spatial variability, with the most variable areas being those with intermediate noise levels. In general the spatial variability accords with the results obtained by SENKO and KIRSHNAN (1971) in New York. It has also been possible to examine within-day temporal variability as a function of area type, although no comparable relationship with mean noise levels was discerned. The most prominent sources of noise have been classified by the five groups of TAE types, and it has been found that traffic noise predominates in some 61% of sites overall, a result that accords with the findings of other workers in the UK (ATTENBOROUGH et al 1976, GILFORD and NORRIS 1973). A variability in the relative prominence of different types of source in the five groups of area types was observed however, and although traffic predominates in all cases it was found (predictably) that a substantial proportion of sites were affected by industrial noise in industrial areas, domestic noise (e.g. children, lawnmowers, dogs) in residential areas, and 'natural' noises (e.g. birds, wind) in semi-rural areas.

(b) <u>Calibration of the TAE prediction model</u>

(i) The model provides a method for predicting the mean ('typical') noise indicator values for TAE zones on the basis of their TAE type. The calibrated model itself is given in Table 5.2. Although the indicator values are expressed in UNL and LNL it has been shown that these indicators may be interpreted as the L_{10} and L_{90} respectively, and that an estimate of the L_{eq} may be obtained from them.

(ii) The noise indicator levels predicted for each TAE type (shown in Table 5.2) are broadly comparable to the levels assigned to equivalent area types in contemporary studies of other urban areas (e.g. TOKYO METROPOLITAN GOVERNMENT 1976, PRICE 1972, ATTENBOROUGH et al 1976). In order of 'noisiness', area types may be listed: commercial, industrial, residential, rural. In common with other studies however (e.g. ATTENBOROUGH et al 1976, GILFORD and NORRIS 1973) it has been shown that the BS 4142 predictions of L_{90} are subject to considerable systematic error.

(iii) The TAE prediction model is similar in principle to the 'category' prediction models of contemporary research (e.g. ATTENBOROUGH et al 1976, PRABHU and CHAKRABORTY 1978), except that specific attention is given to the geographical delineation, size, and precise typological composition of the zones whose noise levels are predicted. For this reason the TAE prediction model - in contrast to the conventional 'category' prediction models - can be used as the basis for a mapping method.

(iv) The error of estimate of the TAE prediction model has been calculated from the matrix of sampling error components already discussed. The finding that spatial within-zone variability is different in different TAE types implies that each TAE type noise level prediction should have its own error of estimate; this could not be achieved without further extensive survey data however, and so the standard errors given (1.8 dBA and 1.6 dBA for UNL and LNL respectively) are overall estimates.

(v) The indicators UNL and LNL were used because measurements could be obtained from a simple manual sound level meter survey technique derived from the methods of other workers (e.g. PRICE 1972, GILFORD and NORRIS 1973, SCHOLES and SALVIDGE 1973, ATTENBOROUGH et al 1976). Advances in instrumentation now allow the L_{eq} to be measured directly from such meters and this improvement, plus the continued use of UNL and LNL as simple indicators of the percentiles, is recommended for future surveys. The error in interpreting UNL and LNL as the percentiles L_{10} and L_{90} has been shown to be small in comparison with spatial and temporal sampling errors.

(vi) The extent of the spatial variance of noise levels within a given zone means that a high error of estimate is incurred if the (area-mean) model predictions are used to predict noise levels at individual sites. A small case study has shown that this error of estimate could be considerably reduced if a set of 'site-identity' parameter categories was designed and calibrated and used in conjunction with the TAE prediction model. Further research into this is recommended.

(c) Application of the TAE prediction model as a mapping method

(i) The ambient noise conditions of the WMMC have been mapped in terms of five categories or ranges of noise conditions. The categories were achieved by an aggregation process through which the predicted noise levels of the 19 TAE types in the prediction model were grouped. Grouping was achieved through a joint consideration of 'natural' breaks in the distribution of the predicted TAE type noise levels along the 'metric' scale, and the urban fabric consistency of the groups. The resulting map shows clearly the location of the highest noise levels in the commercial and industrial zones, as described (non-spatially) in the TAE prediction model. To the author's knowledge this method of mapping ambient noise levels is unique.

(ii) The method is made possible by the explicitly spatial characteristics of the TAE prediction model (i.e. the geographical delineation of TAE zones). It has been seen that the alternative mapping techniques in contemporary research are complex, require detailed spatially comprehensive data and (in the case of the point-receptor methods) of dubious validity (PRABHU and CHAKRABORTY 1978). By contrast the TAE mapping methodology is simple, economical, uses readily-available spatial data and requires a minimal field survey and analysis

As stated, the above appraisal has been restricted to a consideration of the ambient noise study in isolation from the other attributes and broader perspectives laid out in the research problem. These broader issues are addressed in Chapter 9, and in Appendix D a comprehensive summary of the empirical results of the case studies is given in which the ambient noise characteristics of the TAE types are presented in conjunction with other environmental and general descriptive data.

CHAPTER 6

CASE STUDY OF SULPHUR DIOXIDE AIR POLLUTION

6.0 INTRODUCTION

This chapter describes the empirical case study of sulphur dioxide air pollution conditions in the WMMC in which the TAE mapping methodology was tested. In contrast to the ambient noise study it was not possible for the empirical work to be conducted upon primary data because a field survey was not feasible. Consequently the National Survey of Air Pollution was used as a source of secondary data. The number and location of National Survey monitoring sites in the WMMC was not appropriate to allow the TAE methodology to be tested directly, and it was necessary to use the data to calibrate an urban diffusion model in order to achieve predicted concentrations of sulphur dioxide for TAEs in the WMMC; a sample of these predictions was then used to test the TAE methodology. It will be seen that the 'intermediary' role of the urban diffusion model means in effect that the TAE hypothesis was tested in two stages. Furthermore the urban diffusion model itself represents an alternative mapping method to the TAE methodology, and it is necessary for the two quite similar alternatives to be compared and contrasted.

6.0.1 The Empirical Research Method

(a) Aims

The general aim of the study was to test the TAE methodology in the case of sulphur dioxide air pollution. Since the empirical data upon which the tests were made were obtained from an urban diffusion model, and since such models represent a substantial body of knowledge and technique for the mapping of air pollution conditions, it is necessary to examine air pollution modelling methods in general, and the diffusion model in particular, to provide a basis of contemporary knowledge through which the TAE methodology may be developed and evaluated.

(b) Objectives

The principal objectives in testing the TAE methodology remain as they were with noise, viz (i) to validate the hypothesised environment/TAE relationship for sulphur dioxide, (ii) to calibrate the TAE prediction model in terms of the typical mean sulphur dioxide concentrations in each TAE type, and (iii) to apply the model as a mapping method. The empirical development of the urban diffusion model becomes a major objective however, replacing the field survey methods and statistical data analysis exercise that featured in the ambient noise study.

(c) Hypotheses

The central TAE hypothesis follows the familiar format, asserting that the variation in the mean sulphur dioxide concentration of zones over the study area is significantly associated with the variation in the TAE type of the zones. The urban diffusion model is implicitly based upon a similar hypothesis, that the mean concentration of sulphur dioxide in a given zone is dependent upon the urban fabric characteristics of that zone, and also surrounding zones from which pollution is diffused. Thus the conventional 'sulphur dioxide emissions inventory' of the urban area is replaced by an inventory of urban fabric types, each of which possesses a calibration coefficient describing its 'typical emission strength'. It will be seen that in effect the only differences that exist between the TAE hypothesis and the urban diffusion model hypothesis lie in the urban fabric typologies used in each case, and the inclusion of a diffusion function in the latter method. A research sequence was pursued in which firstly the diffusion model is validated, calibrated and used to predict concentrations for TAE zones, and secondly a set of 'sample frame' zones is selected and their predictions used as the data for testing the TAE hypothesis. Thus the TAE hypothesis is effectively tested in two stages; firstly, the principle is tested in the validation of the urban diffusion model, and secondly the precise format is tested in afurther analysis of the diffusion model results.

(d) Tests

The TAE hypothesis is tested by the classical 'analysis of variance' F-test using the data from three sample TAEs of each type in a manner similar to that applied in the ambient noise study. The hypothesis implicit in the diffusion model was tested as part of the procedure through which the emission coefficients and diffusion parameters of the model were calibrated. The urban fabric data were assembled in the nature of a set of independent variables according to the diffusion model format, and these were correlated with the observed sulphur dioxide concentrations at the 36 National Survey sites in the WMMC using multiple regression analysis, a test of the significance of the 'best fit' correlation therefore providing a test of the diffusion model hypothesis. Just as the empirical data collection and analysis exercises in the ambient noise study yielded a number of additional contributions to theoretical knowledge, so the urban diffusion model, through which data for testing the precise format of the TAE hypothesis was formulated, itself constitutes a contribution to theoretical knowledge, particularly in its use of urban fabric data as a surrogate 'sulphur dioxide emissions inventory'.

In the comparison between the TAE methodology and the urban diffusion model it will be seen that between-zone diffusion is relatively small for zones the size of the TAE - a necessary theoretical condition for the essential concept of TAE 'functional zone independence' to be maintained. The comparison also allows the isoline and choropleth mapping techniques to be compared, for it will be seen that the urban diffusion model data output may be expressed in isoline form, in contrast to the choropleth grid square form of the TAE mapping methodology.

As already mentioned in Chapter 4.1, sulphur dioxide was selected as the case study pollutant inter alia because empirical secondary source data was readily available. Although sulphur dioxide is becoming less important as an air pollutant because of recent trends towards lower concentrations - in the UK at least - the case study of this pollutant is of more general relevance since the methodology itself might be applied to other ambient air pollutants, such as heavy metals, which are of increasing importants (see Chapters 4.1 and 9.2).

6.0.2 Synopsis of the Chapter

A broad summary of the methodological issues encountered in any attempt to measure and represent the sulphur dioxide conditions of an urban study area is given in section 6.1, and the problems surrounding the irregular temporal variation in concentrations are seen to make short-term sampling inappropriate as a method of estimating the long-term means, therefore limiting the research to the use of secondary, continuously-monitored data. The following section reviews the wide-ranging methods through which contemporary studies have obtained mapped data of sulphur dioxide conditions, these therefore being seen as alternatives to the TAE mapping methodology. The nature of the 'Modified Gifford' box model, which formed the basis of the urban diffusion model through which data for testing the TAE methodology was obtained, is described together with the criteria for its selection from the wide range of models available in the literature. The testing of the TAE hypothesis is described in section 6.3, together with the calibrated TAE prediction model, and this is followed by a detailed account of the urban diffusion model, centering on the empirical method for calibrating the diffusion parameters and the emission coefficients of the urban fabric activity types; the model is also compared in some detail with the TAE methodology. Section 6.5 describes the mapping exercise, comparing the results of both methods in producing isopleth and choropleth maps of the WMMC, while a more general summary and appraisal of the TAE methodology, in comparison with the urban diffusion model and other contemporary methodologies, is given in the concluding section 6.6. Technical details relevant to this chapter are given in Appendix C.

6.1 THE BASIC PROBLEMS IN MEASURING AND REPRESENTING SULPHUR DIOXIDE AIR POLLUTION CONDITIONS

In principle the problems in measuring and representing sulphur dioxide air pollution conditions are equivalent to those facing the study of urban ambient noise. There are differences however and these substantially affect the methodology which is devised for dealing with them; consequently the empirical approach for testing and assessing the TAE methodology shows considerable differences from that used in the ambient noise study.

6.1.1 Comparisons Between Ambient Noise and Sulphur Dioxide Studies

The most notable difference between the two fields of study is the vastly greater knowledge relating to methods for determining the pattern of sulphur dioxide conditions. These methods, like those for ambient noise, involve both measurement-based and predictive techniques, but are more numerous in the literature and have received deeper theoretical and more extensive empirical analysis. A separate, detailed consideration of the methods is therefore made necessary; this is given in the following section 6.2.

The spatial and temporal variation of sulphur dioxide concentrations dominates the measurement and representation problem just as it does in the case of ambient noise. Consequently SAFEER's (1973) summary of the issues relating to noise (quoted in section 5.1.1) is equally applicable to the sulphur dioxide case - namely, to what extent are sulphur dioxide measurements sampled at a point for a given time period representative of the conditions at that point over some longer period, and of the conditions over a wider area? It should be noted that the TAE methodology, in its response to the spatial issues, is also still concerned with the association of observed conditions to the generative characteristics of area-sources, identified by their urban fabric (TAE) types, rather than individual sources.

The differences between the two fields of study are made evident in the nature of the spatial and temporal variations. The nature of the temporal variations in ambient air pollution conditions is such that variations are far less stable and predictable and are far larger than were found in the case of the noise climate. Concentrations vary markedly through the day with no 'working day plateau', and in addition there is a further complex and major variation between days which is primarily due to essentially unpredictable meteorological vagaries combined with more systematic seasonal changes (see section 6.1.2 and Appendix C.1). Consequently the notion of the 'working weekday' as a suitable 'climatic period' is inapplicable and observations taken for a short period of the day - or even for a full 24 hours of a given day - cannot be considered as meaningfully representative of any long-term 'climatic period', due to the very high temporal sampling error.

This means that air pollution data whose purpose is to represent the climatic or typical spatial pattern must be sampled - and preferably monitored - over a long period, for example a season or a year. This demand is compounded by the fact that instrumentation methods for sulphur dioxide measurement are more appropriate to longer-period observations. With noise it is a simple matter to observe variations in sound level over a matter of seconds, from which it is possible to consider the short-term variations of ambient noise within the sample period as a statistical phenomenon through which a distribution of noise levels is obtained that may be represented by distributional statistics such as the percentiles L_{10} and L_{90}. Such a notion is not possible in the measurement of air pollution however since the instruments commonly operate in a cumulative rather than instantaneous manner; depending upon the sensitivity of the measurement method, the air volume sampling rate, and the airborne concentration of the observed pollutant, it takes a certain time to accummulate a quantity of pollutant sufficient to allow accurate measurement. Although it is possible to make usefully accurate measurements of sulphur dioxide over periods of an hour or less (BERRY et al 1974, GARNETT 1967), the standard monitoring methods for the UK and elsewhere provide for a cumulative 24-hour sampling period (WARREN SPRING LABORATORY 1974, PRAHM and CHRISTENSEN 1977)[1]. Measured values of sulphur dioxide therefore represent the mean concentrations of sample periods which are quite long compared with those for ambient noise.

These factors of temporal variation and instrumentation combine to make the kind of survey used in the ambient noise study totally impracticable. The nature of the instrumentation alone would render this so, and considering also the additional problem of temporal variation it is evident that long-term (seasonal or annual) monitoring stations must be set up in order to obtain accurate 'climatic' measurements. The resource-commitment associated with this long-term monitoring approach vastly reduces the number of sites which it is feasible to observe in a given study area in comparison to what is possible with short-term sampling, to the point where the National Survey of Air Pollution succeeds in maintaining just 36 sites within the WMMC on an annual basis.[2] This figure must be

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1. In some studies of heavy metals, five or seven days are considered more appropriate (BARRATT 1975), due to the low concentrations of the pollutants.

2. Even special studies of moderately-sized cities like Sheffield, Reading and St. Louis (USA) have managed no more than 50 sites (GARNETT 1967, MARSH and FOSTER 1967, PETERSON 1970).

contrasted with the 700 sites which were observed by one surveyor in an eight-week period for the ambient noise study. The capacity for the investigation of the spatial variance of sulphur dioxide conditions is thus severely limited by the ability to obtain data at a high sampling density over a large, County-sized study area. This problem is mitigated somewhat by the fact that by taking long-term means the spatial variation of conditions is reduced from that obtaining on, for example, any given day. This follows from the diffusive nature of air pollution and the fact that over a long period of time the variations in wind direction, speed, and other atmospheric properties affecting dispersion are such as to weaken distinctive zonal or localised characteristics through lateral dispersion and advection and a directional averaging effect.

As stated in the introductory section, the empirical case study was restricted to the use of the data from the 36 National Survey sites in the WMMC; section 6.4 describes how these data were used to calibrate a diffusion model enabling predicted sulphur dioxide concentrations for every TAE in the WMMC to be obtained.

6.1.2 Discussion of the Temporal Variation in Sulphur Dioxide Conditions

Since it has been argued that the nature of the temporal variation of sulphur dioxide conditions has a crucial effect on the possible empirical methodology by making short-term sampling inapplicable, it is necessary to describe the process in more detail in order to substantiate the proposition. The key questions are, as with ambient noise, (a) what causes concentrations to vary over time, and (b) what phases are discernable in the observed variation. These are examined in turn.

(a) Causes of variation

It will be seen in section 6.2 that the general theoretical understanding of the dynamics of urban air pollution states that the pollution concentration obtaining at any given point is dependent upon, (i) the strength of local sources, and (ii) the nature of the dispertion of pollutants from those sources. From this conceptual theoretical model it follows that variations in the observed concentrations can be caused by two key factors, (i) variations in emissions, and (ii) variations in the dispersive properties of the atmosphere. These are now examined.

Emissions of sulphur dioxide in the UK arise from a number of different types of source.

Fig. 6.1 Diagram showing relative magnitudes and trends in types of sulphur dioxide emissions in the UK (Source: WEATHERLEY 1976)

The principal 'source types' are shown in Fig. 6.1, which also gives the recent trends in the relative magnitudes of the emissions in the UK. It should be noted however that the diagram does not show the relative contribution of the various sources to ground level pollution concentrations, since the emission height will effectively control the amount of dilution that takes place before the pollutant reaches ground level. For example, a given quantity of pollution from a high stack emitter (like a power station) will diffuse over a wide area but contribute relatively low concentrations to any given ground-level point; the same quantity of pollution emitted at a low level (from a commercial or domestic space heating source for example) will contribute high ground-level concentrations but only to a limited area in the vicinity of the source. From this it is evident that variations in the emission rates of different source types will differently affect the resulting ground level concentrations of pollution. There is also a clear basic difference between the annual emission cycles of the two basic types of activity which cause sulphur dioxide emission. These basic activities are (i) power-generation, to supply industrial processes and transport, and (ii) heat-generation, to supply the space heating needs of commercial, industrial and domestic buildings. Evidently emissions from the former are seasonal and related to air temperatures, while those from the latter are seasonally constant.

A number of meteorological factors affect the dispersion of air pollution. Chief amongst these are windspeed and atmospheric stability (SCORER 1965, PASQUILL 1971), although wind direction variations will also affect concentrations at individual sites as discussed in Appendix C.3. Concentrations have been found in general to vary inversely with windspeed (MARSH and FOSTER 1967, GIFFORD and HANNA 1973, ELSOM and CHANDLER 1978), while five 'stability classes' have been devised (PASQUILL 1961, 1971) to describe the range of atmospheric turbulance conditions which occur, essentially in accordance with two atmospheric stability parameters, the lapse rate[1] and the vertical mixing height[2]. Between them these parameters 'control' the extent to which the lower atmosphere is mixed, and hence the extent to which pollutants introduced into it are dispersed. Clearly the changable nature characteristic of maritime temperate climates such as that of the UK leads to major variations in the dispersive properties of the atmosphere taking place from one day to the next on an essentially random basis (the effect of these on day-to-day pollution concentrations is shown in Appendix C.1). There is however a 'lag time' in the response of pollution concentrations to changes in atmospheric stability that has been reflected in the identification of a significant 'persistance parameter' (ELSOM and CHANDLER 1978), through which pollution concentrations on a given day are shown to be significantly associated with the previous day's concentrations.

(b) Phases of variation

Three classes of variation may be discerned: (i) annual, (ii) between-day, and (iii) within-day. A detailed analysis of these is made in Appendix C.1 in relation to the causal factors already discussed, and a summary is given here.

The annual cycle is dominated by the emissions trend, changes being due to the space heating component which peaks in January and falls to near zero in high summer. Seasonal or monthly anomalies however perturb this otherwise smooth trend and are due to particularly persistent disturbed or settled meteorological conditions. The between-day class is not cyclical except for slight weekend/weekday variations associated with industrial and commercial emissions (DEMUYNK and DOMS 1975). The main cause of

1. The lapse rate describes the change in temperature with altitude.
2. The vertical mixing height is an altitude which acts effectively as a 'ceiling' with regard to vertical pollution dispersion.

variations is the essentially random changes in meteorological conditions over periods of at most just a few days. Within a given day variations occur in association with the regular cycle of emissions associated with behavioural activity patterns in all types of source. In addition there is commonly a diurnal 'stability cycle' which frequently results in a bi-modal trend in concentrations giving pollution 'peaks' shortly after dawn and around sunset, and 'troughs' in early afternoon and the early hours of the morning. Further to these three phases of variation there are particular anomalous events which may give rise to exceptionally high concentrations, for example inversion and 'fumigation' episodes.

6.1.3 Selection of the Climatic Period

Two points may be noted as arising from the discussion of temporal variability in sulphur dioxide conditions. Firstly, as already stated, a long sample period - preferably a monitoring process - should be conducted in measurement, in order to reduce the sampling error. The second is a related point: in attempting to predict pollution levels, as the time period of the predicted concentrations decreases so an increasing amount of information is required describing the stability of the atmosphere, the distribution of windspeed and direction, and the variation in the emission rates and locations of particularly prominent sources; this follows since short-term concentrations are particularly dependent upon the specific conditions obtaining at the given time. Consequently models for predicting short-term concentrations require specifications which allow the inclusion of these parameters, while models for predicting long-term mean concentrations over a 'climatic period' may take such parameters together as a single 'typical' representative constant, and so are therefore much simpler in their specification and the empirical effort necessary for calibration.

It was stated in Chapter 3.1.4 that the selection of an appropriate and practicable 'climatic period' is the result of both operational and theoretical criteria. Evidently there are two operational criteria - the measurement issues as discussed earlier, and the prediction issues described above - that imply the need for a long-term 'climatic period'. In addition the theoretical criterion of the repeatability of conditions over equivalent climatic periods, as established in Chapter 3.1.4, leads to the conclusion that the climatic period should be at least of seasonal duration, in order to minimise or 'average out' the anomalous perturbations caused by irregular meteorological vagaries. As a result it was decided that half-yearly winter mean conditions (the average of all 24-hour mean concentrations over the 'climatic period' October-March) should be used in the research. This period was taken to comply with the criteria for a 'climatic period' as given above; in addition the period includes the emissions from both 'process' and 'space heating' activities and is therefore more useful in reflecting the pattern caused by both activities than, for example, the summer mean which is predominantly affected by 'process' emissions. Furthermore, the winter mean is the indicator commonly represented in other equivalent studies (e.g. WARREN SPRING LABORATORY 1974, MERSEYSIDE COUNTY COUNCIL 1976, WOOD et al 1974), mainly because the policy-objectives of such studies are usually concerned with the health effects of air pollution, and therefore attention is concentrated upon the periods when pollution levels are highest and so pose the highest risk to health.

The influence of temporal variation on the study of sulphur dioxide conditions has been explored in this section. Having established the winter mean as the climatic period indicator, the chapter now proceeds to examine the extensive methods available for tracing the spatial pattern in ambient air pollution conditions.

6.2 URBAN AIR POLLUTION MAPPING METHODS

The introduction to this chapter has stated that it was necessary, owing to the inadequacy of observation data, to develop an urban diffusion model in order to obtain predicted sulphur dioxide concentrations for a sufficient number of TAEs to allow the TAE hypothesis to be tested. This section summarises the many air pollution mapping methods that have been developed in contemporary research. The methods are compared with the TAE methodology, and in the process are reviewed with respect to their potential as urban diffusion models for this research.

As with ambient noise, the spatial pattern of air pollution conditions may be determined either through measurement-based methods or predictive techniques (c.f. section 5.1.1). Both approaches are well represented in the operational context of local government, with the essential contrast between the rationales of each being well summed up by the views of two workers in this field. BALL (1978a) justifies the Greater London Council's extensive work on urban-scale diffusion modelling by the consideration, 'why measure when it's easier to predict?'; in contrast, BARRATT (1978) argues for Birmingham Metropolitan Borough's wide-ranging observation methods with the view, 'why predict when it's more reliable to measure?'. The differences in outlook are doubtless due to a number of factors, including available resources and expertise, context and purposes of study, and differences in the appraisal of the extent of the errors involved in each approach. Because this research was principally concerned with predictive techniques particularly in connection with the investigation of causal relationships, this type of approach receives the most attention.

6.2.1 Predictive Techniques

In principle the predictive models seek to reflect the theoretical knowledge of the dynamics of urban air pollution in terms of a relationship between pollution concentrations at a given point or area and certain causal factors involving the location and strength of sources and the nature of the dispersion of pollution from source to receptor. As with noise, there are both point-receptor and area-based techniques which will be discussed in the context of the various dispersion theories.

(a) Gaussian dispersion theory

The simplest example of the application of this most important and long-standing theory is in the determination of pollution concentrations downwind of an isolated, single emission stack. The theory was pioneered by REYNOLDS (1895) and developed during the inter-war years by ROBERTS (1923), SUTTON (1932) and TAYLOR (1935), leading to the now-conventional 'Gaussian Plume Model' based on the statistical equation due to SUTTON (1947). In this model the pollution concentrations plotted through the transect of a plume are taken to resemble a Gaussian distribution, with standard deviation values which are parameters of atmospheric stability. Standard expressions of the model have been used in many localised applications, for example in the determination of the location and value of the points of maximum ground-level concentration downwind of large, prominent sources like power stations (e.g. MARTIN and BARBER 1967, CSANADY 1973, NOLL et al 1977), or alternatively in planning the necessary stack height and location required of a given source if certain specified standards are to be met (e.g. TURNER 1970, SKIBIN 1975).

Modifications are necessary however if the theory is to be applied to typical urban sulphur dioxide problems where complex multiple-source emissions are found. Early simplifications by LUCAS (1958) and ALDERTON (1962) involved integrating the Gaussian equation over a hypothetical array of sources within certain boundary conditions delimiting the 'city' source. A parallel and seminal development was that of the 'area-source emission inventory' approach (FRENKIEL 1956, POOLER 1961), in which all emissions within a unit of area are approximated to a single point-source emission of the same net emission strength located at the centre of the unit. Urban-scale predictions are obtained by adding the resulting set of individual Gaussian-model predictions. In this way, typical urban areas containing a multiplicity of small, low-level sources (domestic chimneys for example) are reduced to manageable components. Subsequent to the development of this approach, OZOLINS and SMITH (1966) suggested that prominent elevated sources might be treated individually so that the urban-scale emissions inventory consists of a dichotomy of point and area sources.

This principle forms the basis of the most advanced urban-scale Gaussian models, for example the 'Climatological Dispersion Model' (CDM) developed for the United States Environmental Protection Agency by BUSSE and ZIMMERMAN (1973) and subsequently used in London (BALL 1978b) and Copenhagen (PRAHM and CHRISTENSEN 1977). This model "determines the long-term (seasonal or annual) quasi-stable concentrations at any ground-level receptor, using average emission rates for point and area sources and a 'joint frequency distribution' of windspeed, wind direction and stability categories" (CALDER 1973). An emission inventory for the area under study is thus required, and the method commonly used for achieving this is that adopted by BALL (1978b). The fuel consumption figures for all point sources above a certain threshold emission level are obtained, together with details of the temporal consumption pattern. The remaining fuel consumption for the area, obtained from fuel distributors, is apportioned to area zones on the basis of their land use type, these then being treated as low-level area sources. The CDM allows pollution concentrations to be computed for selected ground-level sites without need of calibration or any reference to measured concentrations.

Undoubtedly the CDM is a highly versatile and robust prediction method capable of determining point-receptor concentrations under a wide range of assumed meteorological conditions. It does however require an extensive emissions inventory data collection exercise which, while not forbidding (BALL 1978a), nevertheless represents a substantial commitment of time and resources for the average local authority, and for the purpose of representing the general pattern of conditions over a study area produces highly detailed results which may be superfluous for the more general policy contexts. It is suggested that the TAE methodology and the urban diffusion model of this research achieve considerable economies in time and resources in comparison with the CDM, with little significant loss in overall accuracy (see section 6.6).

(b) The 'box model' theory

This alternative theory holds that the dynamics of air pollution "might best be described in terms of the mass transfer of material uniformly distributed within discrete geometrical volumes" (REEIQUAM 1970). The process is described by a "differential diffusion equation" (LAMB and NEIBERGER 1971), analogous to the hydrodynamic Green's Theorem. It avoids the Gaussian theory's most untenable assumptions, for example the representation of area-source emission and diffusion by point-source approximation (RAGLAND 1973), replacing them by the assumption of homogeneous pollution concentrations within the 'box' volumes, emission being taken as a steady effusion from the ground-planes of the boxes. These assumptions are generally most tenable for transportation at the meso-scale[1] or greater, and for urban-scale accumulation episodes (i.e. during 'inversions') and it is to these circumstances that the box model is commonly applied.

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1. Meso-scale distances are approximately 10 - 50 Km.

(c) Area-source emission proportionality theory (the 'Gifford' Model)

The general solution of box model differential diffusion equations is still a complex mathematical task however, and a highly simplified version of the theory with between-box diffusion ignored, has gained support in studies of general urban scale pollution. Termed the 'area-source emission proportionality model', or 'Gifford' model after one of its chief proponents (GIFFORD and HANNA 1973), it holds that the ground-level concentrations of a given unit of area are determined solely by the strength of the emissions within that zone. Thus it is held that if a study area is divided into a configuration of zones the emission strength (per unit area) of each is known, the corresponding pollution concentration C of each zone may be calculated from the simple relation,

$$C = K E \qquad 7.1(a)$$

where K is a calibration constant and E is the emission strength of the zone. Interestingly, in view of contemporary attention, this is precisely the concept that was used by MEETHAM (1945) in the very earliest study of urban-scale pollution. It will also be noted that it is conceptually identical to the TAE methodology with pollution conditions of zones being determined by the within-zone characteristics which generate the pollution. In air pollution studies however the use of urban fabric characteristics as surrogate 'emissions data' has been limited generally to population density and building density, as discussed later in the chapter. The Warren Spring Laboratory have developed a system for classifying sulphur dioxide monitoring sites by the urban fabric characteristics of the area around the site, but this classification system has not been used explicitly as a quantitative prediction method and its purpose is restricted to the provision of a descriptive classification of sites (WILLIAMS 1978). Nevertheless it represents a similar approach to the TAE hypothesis and the typology, given in Table C.3 in Appendix C, was used in the development of the TAE typology. A 'Gifford model' approach that has used urban fabric area types as a surrogate 'emissions inventory' is described by MYRUP and ROGERS (1976); however it was designed specifically for the (urban-scale) prediction of traffic-related pollutants (such as carbon monoxide), and so the typology of areas, given in Table C.2 of Appendix C, is not applicable to the study of sulphur dioxide. Methodologically however the Myrup and Rogers study has a greater similarity to the TAE approach than any other study in the literature.

The Gifford model's advantage of computational simplicity is supplemented by an effective performance: "the simple models are as highly correlated with measurements as the more complex models ... it is difficult to achieve results surpassing those of the simple models" (TURNER 1973). The intrinsic simplicity of the model means that factors affecting variations in concentration are approximated to average values and summarised in a single calibration constant; consequently the Gifford model is more suitable to the prediction of long-term means.

Essentially the principle of the TAE prediction model is identical to that of the Gifford model, with the emissions inventory expressed in terms of TAE types.

(d) The 'Modified Gifford' model

The two key assumptions of the Gifford model are, (i) that homogeneous area-source emissions and concentrations obtain within zones, (ii) that there is no diffusion between zones. A trade-off relationship exists between these with respect to the selection of the appropriate zone size, since large area units[1] are needed in order to encompass all sources which

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1. GIFFORD and HANNA (1973) use "city-scale" units, TURNER (1973) applies 10 Km X 10 Km grid square units.

contribute significantly to the concentrations at any given point, and yet areas approaching this size are decreasingly likely to exhibit homogeneous emissions and concentrations. TURNER (1973) attempted to resolve the problem by abandoning the assumption of there being no between-zone diffusion. A simple expression of between-zone diffusion allowed the zone size to be reduced to around 1 sq. Km., where homogeneity is more tenable. As well as giving more spatially detailed results, Turner found that the 'Modified Gifford' model produced more accurate predictions. A similar type of model has been developed by SHARMA (1975) from the integration of a line-source emission equation.

As stated, it was necessary in the research to select and apply a diffusion model in order to obtain sulphur dioxide predictions for the TAE units. The Modified Gifford model was chosen as the basis for this, because (i) it is founded on area-source emissions alone, and is therefore more suited to the TAE form of the 'emissions' data in the research, and is in this case more valid than the point-source-based Gaussian theory, (ii) it is intrinsically and computationally simpler than the urban-scale Gaussian models (e.g. the CDM) and the basic box model differential diffusion models, but with little apparent loss of accuracy in the type of long-term, urban-scale application encountered in the research, (e.g. TURNER 1973, PRAHM and CHRISTENSEN 1977), (iii) it requires only simple input and calibration data of a kind that is available to the average local authority, and (iv) it allows the prediction of the mean concentrations for TAE-sized units, an application which is of questionable validity and accuracy if the simple 'no diffusion' Gifford model is used.[1] The

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1. By comparing the results of the TAE methodology (equivalent to the Gifford model) with those of the Modified Gifford model, the research has subsequently shown that the loss of accuracy in the former is comparatively small (see section 6.4).

principle of the model as applied to the research is summarised in section 6.3.1, and the detailed method described in section 6.4.

6.2.2 Measurement-based methods

It was noted in Section 6.1.1 that the nature of the temporal variation of sulphur dioxide was such that long-period (seasonal or annual) sampling or monitoring was required in order to obtain an accurate representation of conditions over the 'climatic period', and that this imposed considerable limitations upon the number of measurement sites that were feasible within a study area. In consequence the techniques whereby spatial pattern may be inferred from measured data alone are similarly limited. The measurement-based isolining techniques involve the implicit assumption that the data are spatially autocorrelated (see Chapter 3.2.1) and it has been suggested that long-term measurement site densities of at least one site per sq. km. are needed in urban areas if this assumption is to be valid; in addition the sites should be regularly spaced (MARSH and FOSTER 1967, GARNETT 1967, GOLDSTEIN and LANDOWTZ 1977). The literature shows that only in the special study of moderately-sized towns have these conditions proved feasible. Other workers have attempted to replace chemical measurement methods by biological (e.g. lichen) indicators (SOUTH YORKSHIRE COUNTY COUNCIL 1978a) in order to gain an increase in site density (since the lichens are cheaper to obtain and maintain than chemical monitors), but in doing so they forfeit a considerable amount of metric accuracy.

Seldom is it possible therefore to derive isopleth[1] representations of spatial patterns using the simple manual interpolation technique (for

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1. Isopleths are isolines describing equal <u>concentrations</u> of a property.

examples however, see GARNETT 1967, and MARSH and FOSTER 1967). More sophisticated mathematical techniques have been applied with the objective of detecting broad, underlying spatial trends in the data. For example, ANDERSON (1970) has used the technique of trend surface analysis (CHORLEY and HAGGETT 1965) to obtain an isopleth surface represented by the integer power-series polynomial which best fits the observed data set. Empirical eigenvectors have been used by PETERSON (1970), through which a "smoothing, spatial filtering process" identifies the chief component vectors representing the underlying pattern. A third and more common approach is that adopted in the SYMAP technique in which a 'spatial moving average' value is allocated to sites in the attempt to filter out random spatial variability and emphasise the underlying pattern (CHESHIRE COUNTY COUNCIL 1977, DAVIES and ROBERTS 1976).

The common weakness of the measurement-based methods is essentially the high data demand; it should also be noted that, as with all such methods, a purely descriptive and static account is obtained, with no theoretical knowledge and dynamic understanding of the spatial pattern.

6.2.3 A Mixed Technique: The Warren Spring Laboratory Method

The National Survey sites, supervised by the WARREN SPRING LABORATORY (1974) are neither sufficiently dense nor regular enough to allow spatial pattern to be inferred from the data alone. The laboratory has therefore developed a spatial method which reinforces the simple interpolation technique with a qualitative predictive theory based on the hypothesis that sulphur dioxide concentrations are correlated with the local building density over the surrounding 1 sq. km. area (WILLIAMS 1978).Loosely termed a "mental modelling" method, it involves the researcher firstly assessing the National Survey observations overlaid upon a map of building density, and then interpolating the probable path of isopleths between observation sites considering the spatial pattern in the building density. In this way maps have been derived which cover the whole of the UK (DoE 1976) and which have been used extensively in local authority studies (e.g. MERSEYSIDE COUNTY COUNCIL 1976, CHESHIRE COUNTY COUNCIL 1977, SOUTH YORKSHIRE COUNTY COUNCIL 1978a). The accuracy of the interpolations has not however been properly assessed.

The range of available mapping techniques have now been discussed. A more detailed account may be found in the literature (e.g. STERN 1970), and a summary of model types, applications, data requirements and output, due to BENARIE (1976) is given in Appendix C.2. The extensive range of techniques contrasts with the limited number available in the case of ambient noise. The general value of predictive techniques has been established, and the merits of the simple Gifford model (equivalent to the TAE methodology) in terms of data and computational requirements and data output have been described. The Modified Gifford model has been seen to hold the most potential as a method for aiding the test of the TAE hypothesis.

6.3 TEST OF THE CENTRAL HYPOTHESIS AND CALIBRATION OF THE TAE PREDICTION MODEL

This section describes the test of the central TAE hypothesis and the calibration of the TAE prediction model for sulphur dioxide air pollution. Essentially the procedure through which these two objectives were pursued is identical in statistical terms to that used in the case study of urban ambient noise, and in order to avoid unnecessary repetition statistical principles and procedures are not restated unless they concern different issues or approaches.

To recapitulate, the TAE hypothesis holds that, in the case of sulphur dioxide, the classification of concentrations according to the TAE type of the zones in which they are found explains a significant proportion of the total (spatial) variance of concentrations over the study area; this hypothesis is tested through applying the classical 'analysis of variance' F-test to predicted data obtained from an urban diffusion model. The TAE prediction model is calibrated by allocating mean sulphur dioxide concentrations to each TAE type.

6.3.1 Derivation of Data for the Test and Calibration Exercises

The temporal sampling problems discussed in Section 6.1 make it necessary to achieve measured 'climatic period' data through long-term monitoring, a project that was not feasible in this research. Consequently it was necessary to use data from a secondary source, the National Survey of Air Pollution. The same constraints limit the number of sites that can be maintained by the National Survey, and Winter Mean data were only available at 36 sites within the WMMC. Not only was the data limited in the number of sites observed, but since the survey was not designed specifically to suit the needs of this research the sites were unevenly distributed amongst TAE types, with some types having no sites at all. Clearly therefore no test of the hypothesis could be made using the secondary source data directly. The urban diffusion model was designed as a means to overcoming these problems, acting as an intermediary technique and essentially 'converting' the secondary source data into a form which then allowed the specific format of the TAE hypothesis to be tested in a subsequent F-test.

The model chosen for this task was of the 'Modified Gifford' type, as discussed in section 6.2.1 and in more detail in section 6.4.1 and Appendix C.3. Commonly such models use area-source emission inventories either based on quantitative emissions or simple surrogate parameters such as building density or population density (BENARIE 1976). In this research the emissions inventory was expressed in terms of measures of the urban fabric activity type (consisting of the urban fabric components which were aggregated into TAE types), on the assumption that each activity type could be assigned a 'typical emission strength'. This kind of emissions inventory, which is more detailed than that given by the usual simple surrogate parameters yet much more readily and economically obtained than quantified emissions data, appears to be unique in sulphur dioxide studies. Using this emissions data and a diffusion calibration, the model was able to provide a prediction of the Winter Mean sulphur dioxide concentration for every TAE in the WMMC; the calibration of the model and the specially-written computer programme through which the predictions were obtained are discussed in section 6.4. It should be noted that this 'intermediary data technique' substitutes for the field survey and statistical analysis exercise adopted in the ambient noise study, and represents an equivalent research effort. In effect the urban diffusion model acts as the first stage in the test of the TAE hypothesis, since it is based on the same assumption of an urban fabric/environment relationship. The chief differences between the assumptions of the urban diffusion model and those of the TAE hypothesis are that the diffusion model contravenes the principle of 'functional zone independence' (see Chapter 3.4.2) by allowing between-zone diffusion to be included, and it also involves a different classification of the urban fabric to the TAE typology, allowing, for example, smoke control zones to be included (see Section 6.4.2). Thus while the principle of the TAE hypothesis (the urban fabric/environment relationship) is tested by the urban diffusion model, it is still necessary to adopt the F-test as a means of testing the specific format of the hypothesis.

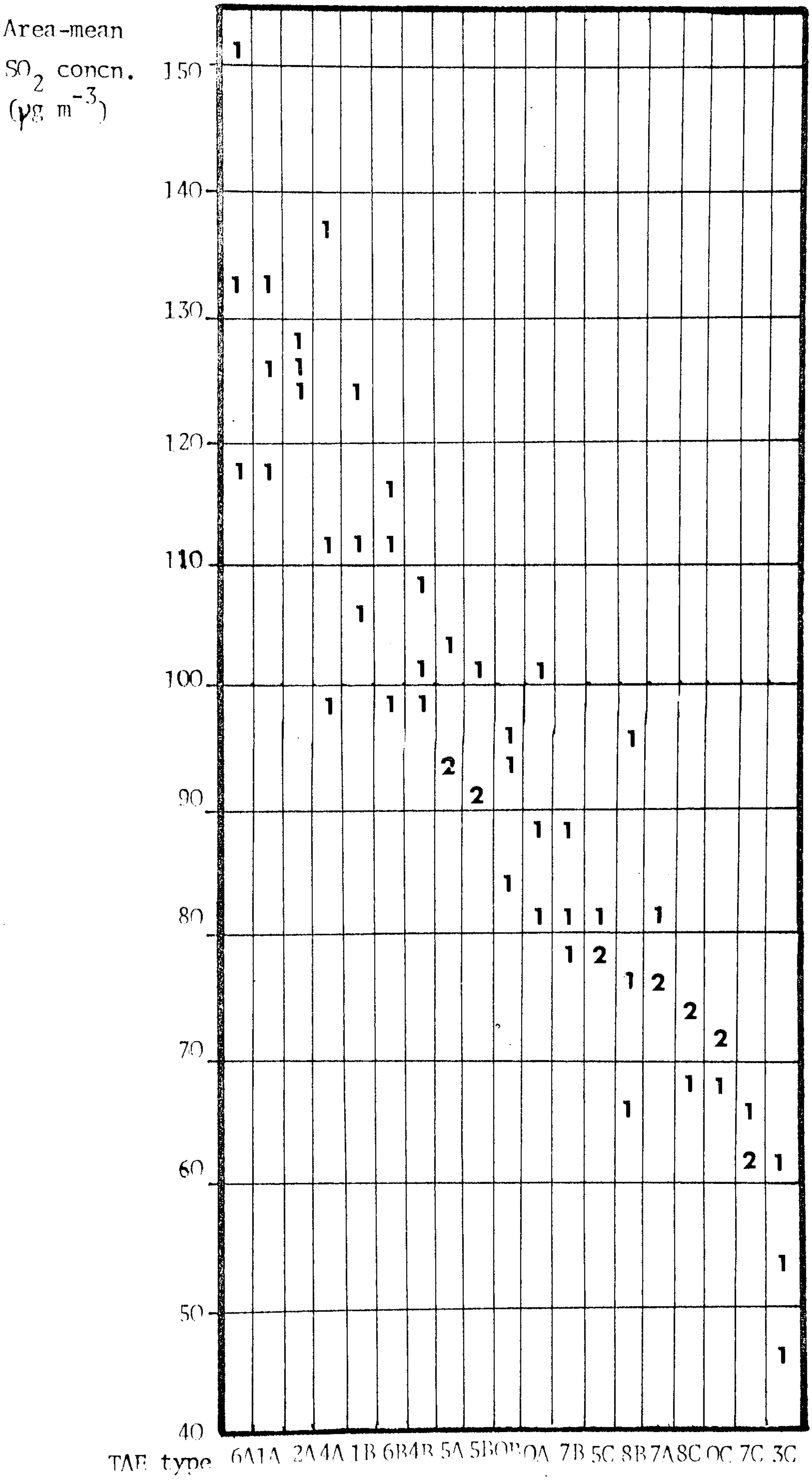
6.3.2 The Test of the TAE Hypothesis

The null hypothesis upon which the F-test was actually made states that sulphur dioxide concentrations sampled from different TAE types come from the same parent population. The data for the test were obtained by randomly sampling the predicted concentrations of three TAEs within each type; the distribution of these samples is shown in Fig. 6.2. The apparently small number of three samples was dictated by a number of factors. Firstly, for some types (6A and 5C for example) there were only three TAEs to be found in the WMMC, and in any case a sample of three TAEs per type amounted to a 10% sample of the whole County. In addition the data for each sample TAE consisted of the predicted mean concentration for the zone, therefore constituting not a single point observation such as those obtained as the individual data items in the ambient noise study, but the mean of the TAE zone's 'population' of point-receptor concentrations; each prediction therefore showed greater statistical reliability than a 'point' data item.

The F-test operated in the manner explained in Chapter 5.2.2, comparing the estimate (B) of the total study area population variance obtained from between-type variance, to that (W) obtained from pooling the within-type variances. From the data summarised in Fig. 6.2 values of B and W were calculated, giving an F-ratio of 12.59. With the appropriate 18 and 38 degrees of freedom standard tables show that the critical F-value at 1% significance is 2.46. Consequently the null hypothesis was decisively rejected and it was concluded that the predicted mean sulphur dioxide concentrations of TAE zones were significantly associated with their TAE type.

In contrast to the ambient noise study, it was not found to be necessary to correct the value of F which was obtained directly from the data; this was because the sampling process did not lead to bias in the calculated ratio. The one possible source of bias was the error in the

Fig. 6.2 Distribution of area-mean sulphur dioxide concentrations in sampled TAE types.



predicted concentrations (discussed later); each data item in the test was associated with an equal error of estimate however, and so although the calculated values of both B and W contain this extra element of variance due to the 'prediction error' in the data items, the errors are distributed randomly and so do not bias the F-ratio. In fact an equal amount of error variance is added to B and W, the net effect being to reduce rather than increase the value of F in relation to that which would be obtained in the absence of error. This strengthens rather than weakens the test, and since the result was nevertheless totally conclusive it was not seen to be materially necessary to obtain a corrected value of F.

6.3.3 Calibration of the TAE Prediction Model

The objective of the TAE prediction model was to associate each TAE type with a representative, 'TAE mean' indicator value, in this case the mean concentration of sulphur dioxide over the Winter period.[1] The TAE mean values were obtained directly from the sample of TAEs described in Fig. 6.2, and are presented in TAE and matrix format in Table 6.1. This matrix therefore constitutes the calibrated TAE prediction model.

The accuracy of the model predictions is assessed through considering the sources of error. Two components are evident: firstly there is the error of estimate associated with the statistical variability of mean concentrations between TAEs of the same type; secondly there is the error - equivalent to a 'measurement' error - that is associated with the data upon which the model was calibrated; this was in fact the prediction error of the urban diffusion model. A value for the first component may be

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1. Other indicators could have been used, for example those concerning extreme values, such as 'concentration exceeded on three days over the period'; but these do not relate to the typical conditions that are of interest to the research.

Table 6.1 Matrix of the TAE Prediction Model for Sulphur Dioxide Concentrations ($\mu g\ m^{-3}$)

LAND USE	ROAD NETWORK DENSITY		
	A. Dense	B. Medium	C. Sparse
0. Residential	90	91	75
1. Industrial	126	114	*
2. Commercial	126	*	*
3. Open Space	*	*	54
4. Res/Ind	115	103	*
5. Res/Comm	97	95	79
6. Ind/Comm	134	109	*
7. Res/O. S.	78	82	63
8. Ind/O. S.	*	79	77

*: Insignificant proportion (less than 0.5%) of total WMMC area.

derived from the pooled variances of the samples within each type; from the data in Fig. 6.2 a standard deviation of 8.7 $\mu g\ m^{-3}$ was obtained. This was taken to be the standard error involved in taking the mean predicted concentration of any given TAE to represent the mean predicted concentration of TAEs of that particular type. The prediction error itself was derived from the urban diffusion model calibration exercise as described in section 6.4.4, where the standard error will be seen to be 15.5 $\mu g\ m^{-3}$ in the prediction of the concentration at any point within a given TAE. A 'sum of squares' addition of the two error components gave a standard error of 17.7 $\mu g\ m^{-3}$, but this then represents the error in predicting the concentration at any point in any TAE of a given type, rather than the error in predicting the area mean concentration within any TAE of a given type. This latter is the error that is ultimately of interest since it is that involved in the TAE prediction model, which predicts the mean concentration of sulphur dioxide within TAEs, and this error will clearly be smaller than the error in predicting point-concentrations. The extent of this reduction will depend upon the spatial variability of Winter-mean concentrations between points within a TAE zone; however the research was not able to quantify this due to the lack of data. Consequently it is not possible to specify precisely the accuracy of the TAE prediction model other than to state that the standard error of estimate lies within the range 8.7 to 17.7 $\mu g\ m^{-3}$.

The prediction model gives variations between TAE types which follow the expectations of contemporary knowledge and theory; these are examined more closely in section 6.5.1. No particular anomalies are evident; the tendency for residentially-based categories (0,5,7) to have higher concentrations in density class B than in class A is probably explained by theoretical factors concerning emissions (as explained in section 6.3.3).

As in the ambient noise study, it is evident that with errors in the range as given above, the accuracy of the TAE prediction model is not sufficient to allow the conditions of each TAE type to be considered statistically distinct from the conditions of all other types. It is quite possible for example that, referring to Table 6.1, the conditions of the residential/open space/medium category (7B) may in fact be lower than those of the residential/open space/dense category (7A). These limitations to the accuracy of the TAE prediction model mean that a cautious approach must be taken when applying the model as intended, to predict the general sulphur dioxide conditions of the WMMC. It was seen in Chapter 5.5.1 that to be consistent with the accuracy of the model the TAE types must be grouped into broader categories of condition (with group intervals at least equal to the magnitude of the 'significant gap' between predicted TAE type conditions) before the model may be reliably applied as a choropleth mapping method. It has also been established that grouping is necessary in any case for display purposes, and the procedure adopted in this research is described in Section 6.5.1. As seen in the ambient noise study, however, (Chapter 5.2.3) a valid aggregate spatial prediction may be achieved through a cumulative frequency distribution constructed upon the TAE prediction model data and the WMMC urban fabric matrix in Table 4.4; the resulting distribution is shown in Fig. 6.3.

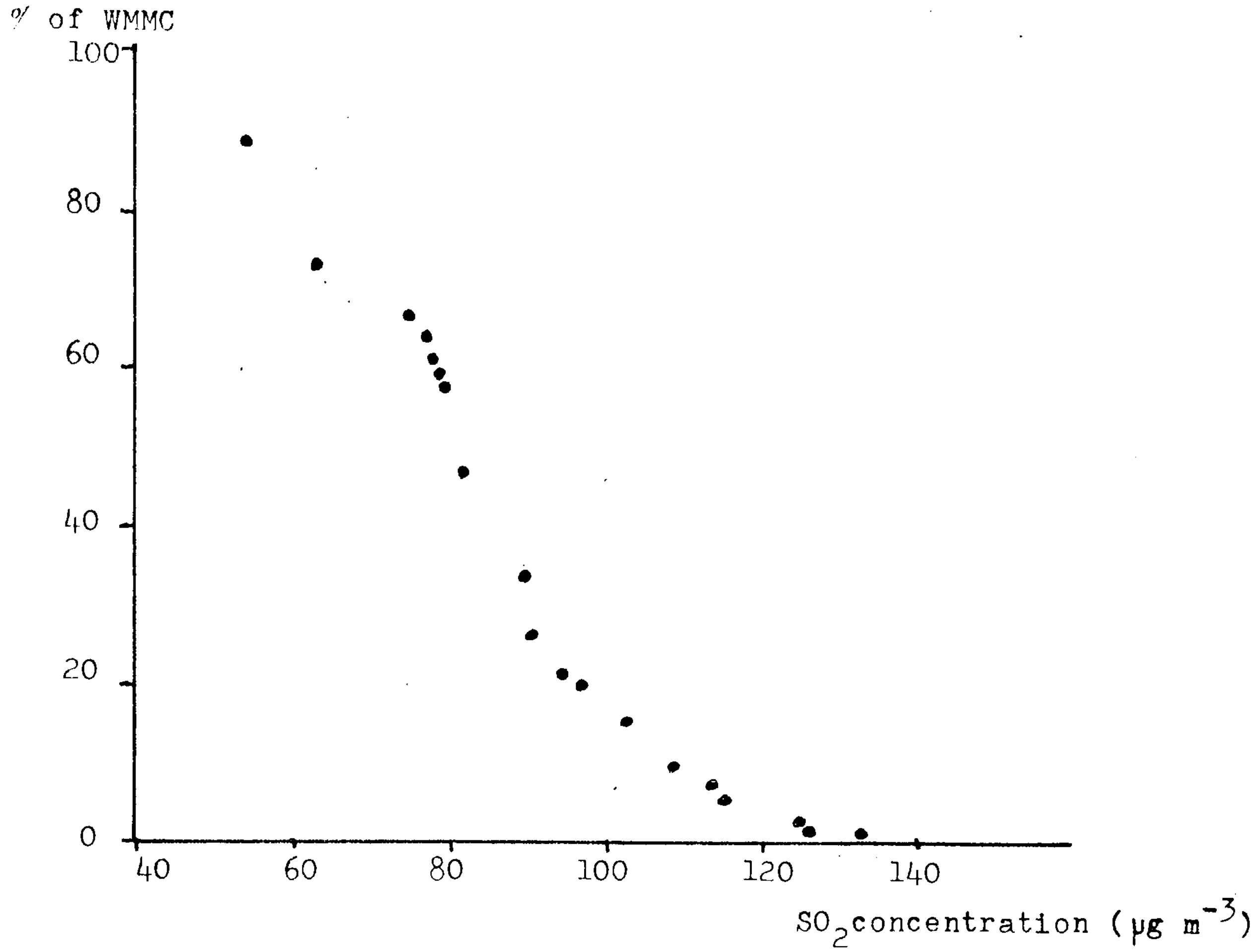

Fig. 6.3 Cumulative frequency distribution of SO_2 concentrations for the WMMC, obtained from the TAE prediction model.

This section has described the validation of the TAE hypothesis and the calibration of the TAE prediction model, and an estimate of the model's accuracy has been given. The application of the prediction model as a mapping method is described in section 6.5; preceding this however the urban diffusion model which gave the data for testing the TAE methodology is discussed. Like the TAE methodology the diffusion model produced a spatially comprehensive prediction of the sulphur dioxide pattern and is clearly an alternative mapping technique; the remainder of the chapter is concerned, where relevant, to make comparisons between the two.

6.4 THE SULPHUR DIOXIDE URBAN DIFFUSION MODEL

In addition to being the main empirical exercise in the sulphur dioxide study, the urban diffusion model represents a further contribution to the contemporary theory of urban air pollution modelling, its most original feature being the incorporation of urban fabric data, calibrated into 'typical emission strengths', as the basis of the urban-scale emissions inventory. The specification and theory of the model is otherwise closely linked to contemporary models of the 'Modified Gifford' type. This section establishes the theory and specification of the model, and describes the two-stage calibration process involving multiple regression against the observed National Survey concentrations and theoretically-derived modifications, and the computer programme which calculated the predicted mean concentrations for every TAE in the WMMC study area. The validity and accuracy of the model are also discussed.

6.4.1 Model Theory and Specification

The essential theory of the 'Modified Gifford' model, and the reasons for its suitability in this research study, have been given in section 6.2.1(d). The chief issues surrounding the theory and specification of such a model as applied to this research are the assumption of area-source emission, the need for a quantified emissions inventory for the study area expressed in the appropriate TAE zone size, and the mathematical representation of the diffusion process.

The assumption of area-source emission (in which large point sources are ignored or included as part of the area-source) is made quite frequently in urban-scale studies, especially when it is the long-term means that are of interest (GIFFORD and HANNA 1973). This assumption is made all the more valid by the fact that although the majority of the sulphur dioxide emission in the UK comes from high level, 'point-source' stacks (see Fig. 6.1), this proportion is less in large urban areas; moreover because the lower level, urban 'area-source' emissions diffuse through a smaller volume of air in reaching ground level, they contribute a disproportionately large amount to the total ground-level concentrations in their vicinity.[1] In order to test the area-source assumption, the data from a study of Copenhagen by PRAHM and CHRISTENSEN (1977) were analysed to determine the relative amounts of the spatial variation in urban sulphur dioxide concentrations due to point and area sources. The results of this study, discussed in Appendix C.3, show that within the study area the emissions from point sources appear to yield almost constant concentrations at the ground-level sites. Thus in this research it was assumed that the spatial variation of concentrations was due to spatial variation in the area-source emissions alone, with point-sources effectively contributing a spatially constant 'background' level over the study area.

In the most sophisticated air pollution modelling applications, the area-source emissions inventory is based on fuel consumption figures for the area zones (e.g. TURNER 1973). In simpler studies surrogate parameters are used, for example building density (WILLIAMS 1978), housing density (MARSH and FOSTER 1967) and population density (PELLETIER 1967 , GIFFORD and HANNA 1973). In this research the emissions inventory was derived from knowledge of the urban fabric composition of the TAE zones, each zone acting as an individual 'area-source'. To quantify the emissions from each zone it is necessary to quantify the 'typical emission strengths' of each urban fabric activity type; ideally these would be expressed in terms of a

1. BALL (1978a) has estimated that 30% of London's sulphur dioxide emission comes from area sources and that their relative contribution to ground level concentration is much higher than this; the Prahm and Christensen study (see Appendix C) indicates that up to 70% of the ground-level concentration in Copenhagen is due to area-source emission.

'pollution mass emissions rate' derived from theoretical knowledge of emissions from the various activity types. Since current knowledge does not extent to this, each activity type was calibrated in terms of a 'relative emission strength' achieved from a combination of empirical and theoretical considerations.

Diffusion between zones is expressed mathematically through a 'diffusion function' which is effectively a multiplier applied to the emissions of zones at a distance category i from a given receptor zone (where i = 0), with the value of the multiplier tending to zero as i increases. The concentration of pollution at a given receptor zone is thus a function of the sum of the emissions from the zone itself and surrounding zones, each multiplied by the relevant value of the diffusion function. This forms the basis of the standard mathematical specification of the 'Modified Gifford' model. The specification used in this research was due to SHARMA (1976) and took the general form:

$$C = D\left\{\sum_{i=0}^{N} Q_i \left[(i+1)^B - i^B\right] + G\right\} \qquad 6.1$$

where C is the predicted sulphur dioxide concentration, D is a parameter dependent upon windspeed, meteorological stability parameters and zone size, B is an atmospheric stability parameter dependent upon both surface roughness and meteorological stability, G is a background constant concentration, and Q_i is the emission rate of the zone at distance i from the receptor zone. Sharma used i = 1km, thus giving a grid of 1 sq. km.-sized zones. In the equation the diffusion function is given by $\left[(i+1)^B - i^B\right]$, which tends to zero as i increases; the values for a given distance i are dependent upon B, such that as B (which is proportional to atmospheric instability) increases, so the value of the diffusion function increases, thereby reflecting greater diffusion in conditions of increased atmospheric instability. Because the diffusion function does not become zero until i reaches infinity it is necessary in practice to impose a limit i=N, to the distance over which diffusion is considered.

Sharma designed the model for use in short-term (24-hour) prediction applications, within which it was assumed that the wind direction was constant. Consequently the parameter i simply describes the i grid zones downwind of a given receptor zone. Because wind direction changes over time it is of course necessary in longer term applications to consider pollution diffusing from all directions, and theoretically it is necessary to 'weight' the diffusion coming from different directions by a factor describing the frequency of that wind direction and the associated typical stability parameters (such as through the 'joint frequency function' used in the CDM; see section 6.2.1(a)). Where the relative frequency of wind direction is reasonably homogeneous however the directional weighting may be ignored, as was done by TURNER (1973) and POOLER (1961). Appendix C.3 shows the wind rose for Birmingham during the study period, from which it was inferred that no significant net directional effect in air pollution diffusion was evident. Consequently the parameter i describes a set of ideally annular zones surrounding the receptor zone; since the data is expressed in a 1 sq. km. grid configuration however, it was necessary to approximate this to a set of square 'nested' zones surrounding the receptor square (as used in the 'diffusion grid' of POOLER 1961) and to modify the grid size to that of the TAE; this is illustrated in Appendix C.3.

The specification of the Sharma model given in Eqn. 6.1 was modified slightly in order to meet the particular circumstances of this research. The dimensionless parameter D becomes a constant (since the research was concerned with a single time period and zone size) and so may be absorbed into the parameters G and Q_i. The concept of Q_i in the research is that of a relative emission strength and therefore it was possible to reduce the diffusion function to a normalised factor Ki describing the proportional contribution of emission in zone i to the concentration in the receptor zone (i=o). The parameter k_i is thus given by:

$$\left(k_i\right)_{B,N} = \frac{(i+1)^B - i^B}{\sum_{i=0}^{N} \left[(i+1)^B - i^B\right]} \qquad 6.2$$

It should be noted that for a given zone i the proportional contribution to the receptor zone is a function of both B and N; thus these parameters effectively control the amount of diffusion allowed by the model. One of the tasks of the calibration exercise was thus to decide on the most appropriate values of B and N for the given study area and study period.

It has been stated that the concept of the 'emission parameter' Q_i is established upon the notion of the 'relative emission strengths' of urban fabric activity types. A set, u, of ten urban fabric activity types was developed out of the TAE typology by considering a rationale discussed in 6.4.2 following and in Appendix C, and the types are listed and coded in Table 6.2. The value of the 'relative emission strength', q_u, of a particular activity type u is given by the concentration of sulphur dioxide that would obtain if type u covered the whole zone. The second task of the calibration exercise was to estimate the values of the set q_u. From this, the relative emission strength of zone i (given by Q_i) is then given by the sum of the proportions of the zone area covered by the activity types u, $(p_u)_i$, multiplied by their relative emission strengths, (q_u), i.e.:

$$Q_i = \sum_{u=1}^{10} (p_u)_i \, q_u \qquad 6.3$$

Thus, applying the modifications given in equations 6.2 and 6.3 to the original Sharma model of equation 6.1, the model becomes:

$$C = \sum_{i=0}^{N} \left(\sum_{u=1}^{10} (p_u)_i \quad q_u \right) \cdot (k_i)_{B,N} + (G)_{B,N} \qquad 6.4$$

This equation gives the specification of the model that was used in this research. It is seen that various parameters must be calibrated;

firstly, the diffusion parameters B and N, and secondly the emission 'coefficient' parameters qu and the background constant G. Initially an empirical calibration was made using multiple regression analysis with measures of the dependent variable provided by the National Survey data. The emission parameters qu were then modified on theoretical considerations before a final calibration was made.

6.4.2 Empirical Calibration Using Regression Analysis on National Survey Data

As stated earlier, National Survey data describing winter mean sulphur dioxide concentrations were available at 36 sites within the WMMC. The empirical calibration exercise involved identifying the 36 TAE receptor zones in which the sites were located, measuring the independent land use activity type variables for each receptor zone, taking the National Survey measurements as the dependent variable and conducting a multiple regression analysis upon the data from the 36 samples. The procedure is explained in detail below.

The independent variables in the regression are the proportional contributions of the ten urban fabric activity typesto the receptor zone. These were obtained from a disaggregation of the activity components from which the TAEs were built up (see Chapter 4.3). There were several advantages in this, over the alternative of using the aggregate TAE typology and assumedly homogeneous zones: (i) a smaller number of independent variables were considered, (ii) the effect of smoke control zones could be included, (iii) the emission strength concept could be related to particular types, rather than combinations, of activity and density, and (iv) greater accuracy could be obtained by disaggregation of the components. Consequently the urban fabric base data for the WMMC was converted so that each TAE zone contained a measurement of the proportion of its area covered by each of the activity types given in Table 6.2 (note

Table 6.2 The Ten Urban Fabric Activity Types u=1, 10 (and Zero Emission Type u=0)

Variable Identity u	Code	Urban Fabric Activity Type; Description
0	OS	Open space, network density A, B and C
1	RA	Residential, Network density A, No smoke control
2	RB	" " " B "
3	RC	" " " C "
4	RAX	" " " A, Smoke Control Zone
5	RBX	" " " B "
6	RCX	" " " C "
7	IA	Industrial, Network density A
8	IB	" " B and C
9	CA	Commercial, Network density A
10	CB	" " B and C

that the 'activity types' take account of both land use and density).

The determination of the independent variable values and the nature of the regression analysis procedure are explained more clearly if the basic model equation is rewritten thus:

$$C = \sum_{i=0}^{N} \left(\sum_{u=1}^{10} (p_u)_i \cdot q_u \right) \cdot (k_i)_{B,N} + (G)_{B,N} \qquad 6.4$$

$$= \sum_{u=1}^{10} \left(\sum_{i=0}^{N} (p_u)_i \cdot k_i \right)_{B,N} \cdot q_u \quad +(G)_{B,N}$$

$$= \sum_{u=1}^{10} \left(r_u \cdot q_u + G \right)_{B,N} \qquad 6.5$$

$$\text{where } (r_u)_{B,N} = \sum_{i=0}^{N} (p_u)_i \cdot (k_i)_{B,N} \qquad 6.6$$

Equation 6.5 shows that r_u (u=1,10) are the independent variables in the regression, describing the proportional contribution of each of the u urban fabric activity types to the receptor zone under any given assumptions of B and N; q_u are the emission 'coefficients' of the urban fabric variables and G is the background constant concentration. Thus if the values of r_u

are determined for each receptor zone from the urban fabric base data, and regressed as the independent variables against the observed values of C obtained from the National Survey data, then the 'best fit' estimates of q_u will be given by the regression coefficients, and the background constant G by the regression constant. These 'best-fit' values of q_u and G apply for the given diffusion conditions described by the assumed values of B and N; by repeating the regression under a range of different assumptions of B and N (leading to a range of different values for k_i, and therefore for r_u) it was possible to compare the explanatory powers of the regression equations obtained in each case, and so to identify the values of B and N which were associated with the highest explanatory power existing between the observed and the predicted concentrations. These values were then taken to be the best empirical estimates of B and N, and the relevant values of q_u and G which resulted from the regression involving these particular diffusion conditions, were taken to be the best empirical estimates of the emission 'coefficients' and the background constant (note that the values of q_u and G change under different assumptions of B and N).

This empirical procedure is summarised in Table 6.3. The determination of the independent variable values r_u is the most critical aspect, and proceeds as follows. Each of the 36 TAE receptor zones containing a National Survey site was identified, and the i 'nested' diffusion zones surrounding it were delineated. Taking the i^{th} diffusion zone, all its constituent TAEs were identified and the urban fabric activity data were aggregated to give the proportions $(p_u)_i$ of the total zone area covered by each of the u activity types (u=1,10). For any given receptor zone, the proportional contributions r_u of each activity type under given diffusion assumptions B and N were calculated by aggregating the proportions within each of the i zones using the diffusion function 'multiplier' $(k_i)_{B,N}$ according to equation 6.6. The values of $(k_i)_{B,N}$ describe the

Table 6.3 Summary of the Empirical Calibration Method

Disaggregate base map urban fabric data to give proportion of each TAE area occupied by urban fabric activity type u(u=1,10) as defined by Table 6.2.

↓

For each receptor zone delineate the i 'nested' diffusion zones, and for each zone i(i=0,N), calculate the proportion p of its area in urban fabric activity type u, to achieve the set $(p_u)_i$.

↓

For given assumptions of B and N, calculate the relative contribution $(k_i)_{B,N}$ of the i zones to the receptor zone concentration.

↓

Calculate the proportional contribution to the receptor zone concentration of each activity type u (r_u) by summing the function $(p_u)_i \; (k_i)_{B,N}$ over i.

↓

Regress the independent variables r_u against the observed National Survey concentrations as the dependent variable using the 36 sample sites.

↓

Achieve 'best fit' estimates of q_u and G from the regression parameters.

↓

Repeat for other values of B and N, and select the values giving the highest regression correlation coefficient; the values of q_u and G for this regression are the best estimates of the emission 'coefficients' and the constant.

(loop back to: For given assumptions of B and N ...)

→ Empirical estimate Calibration of B, N, qu, G.

proportional contributions from zone i to the receptor zone concentration under the diffusion conditions given by B and N. A range of possible values of B and N was selected which encompassed those of other equivalent studies, and for each the diffusion proportions $(k_i)_{B,N}$ were calculated from equation 6.2, giving the results shown in Table 6.4.

Table 6.4 Values of $(k_i)_{B,N}$ for Various Values of B,N and i

Zone Identity i	Values of B and N											
B	B = 0.18				B = 0.25				B = 0.30			
N	0	1	3	5	0	1	3	5	0	1	3	5
0	1.00	.94	.90	.88	1.00	.90	.82	.77	1.00	.84	.70	.64
1		.64	.05	.05		.10	.09	.08		.16	.13	.18
2			.03	.03			.05	.06			.10	.09
3			.02	.02			.04	.04			.07	.06
4				.01				.03				.05
5				.01				.02				.04

The National Survey data used in this research were the 1975/6 Winter Mean concentrations; the location of the 36 sample sites and the concentrations observed at each are given in Appendix C. The regression parameters resulting from the ten multiple regression analyses, run[1] using the different diffusion assumptions of Table 6.4 are also given in Table C.8 of Appendix C, and it is seen that the highest correlation coefficient occurred for the regression with diffusion parameters B = 0.30 and N = 5. These results are consistent with those of equivalent contemporary research.[2] For the regression with these diffusion conditions the regression coefficients and constant were as shown in Table 6.5, which therefore gives the best empirical estimate of the relative emission strengths q_u and the background constant G. The research therefore

1. Regressions were run using the standard ICL XDS3 macro on the Aston University ICL 1904S computer.

2. For example, GIFFORD and HANNA (1973) find B = 0.25 and SHARMA (1976) uses N approximately equal to 6.

Table 6.5 Regression Parameters and Coefficients for the Ten Urban Fabric Activity Type Variables at 99% Significance (for B = 0.30, N = 5)

Regression Parameters	Urban Fabric Activity Types (u = 1, 10) and Codes									
	1(RA)	2(RB)	3(RC)	4(RAX)	5(RBX)	6(RCX)	7(IA)	8(IB)	9(CA)	10(CB)
Coefficient qu ($\mu g\ m^{-3}$)	49	62	28	44	53	57	176	104	85	156
't' value of coefficient	1.42	1.67	1.69	1.26	1.57	1.59	3.27	3.48	2.24	1.78
Parameters	r = 0.809		r.e. = 17.1 $\mu g\ m^{-3}$			K = 35.4 $\mu g\ m^{-3}$				

adopted B = 0.30 and N = 5 as the appropriate diffusion parameters for the study, but for reasons described shortly, the empirically-derived calibration of the other parameters q_u and G given in Table 6.5 was modified by theoretical considerations.

6.4.3 Modification of qu and G Through Theoretical Considerations

Three factors constrain the degree of confidence in the results of the regression-based calibration. Firstly, the theory of multiple regression analysis requires that the indeoendent variables must exhibit no multicolinearity, and the sample data should be dispersed evenly through a sample frame which encompasses the full range of each variable. These issues were examined as discussed in Appendix C.4 where it is seen that while no appreciable multicolinearity is evident, the sample frame is poor for some variables, particularly those in the residential categories. Resulting from this is the second constraining factor, the low 't-value' significance parameter for many variables, as seen in Table 6.5. Only two variables entered the multiple regression at significance levels of 5% and 10%, and though coefficients for all ten variables may be obtained through running the regression at 99% as was done in order to achieve the data in Table 6.5, this leaves little confidence in the overall robustness of the relationship. Finally there is the issue of the errors and approximations in the model itself, particularly the representation of the diffusion process and the treatment of discrete and assumedly homogeneous area units.

Consequently, theoretical criteria were introduced to provide a method of evaluating the reliability of the empirically-derived coefficients. As stated earlier, current theoretical knowledge is not sufficient for quantitative estimates of qu to be made, however a qualitative consideration of the properties of the urban fabric activity types themselves allowed some general guidelines to be set out in relation to the typology of Table 6.2:

(i) Sulphur dioxide emissions from domestic coal combustion should result in generally higher emission strengths in the 'residential uncontrolled' categories than in the 'residential controlled' categories.

(ii) The 'Residential C' category (whether 'controlled' or not) should exhibit a lower emission strength than the 'Residential A and B' categories due to the lower building density and therefore lower source density. It is less evident whether a difference should exist between the Residential A and B categories for although category A has a higher land use intensity than category B, the difference in building density (and by implication source density) is less clear.[1]

(iii) The differential effect of smoke control should be negligable in the 'Residential C' category since the predominently high socio-economic status of category C residents means that extensive domestic coal consumption is unlikely irrespective of the existence of smoke control zones.

(iv) The 'Industrial A' emission strength should significantly exceed that of the 'Industrial B' category, for in addition to the density factor it is also found that the latter category includes peripheral warehousing and the more modern factories where low level emissions tend to be comparatively small.

(v) The 'Commercial A' emission strength should significantly exceed that of the 'Commercial B' category, for in addition to the density factor the former category is associated with the large-scale consumption of high-sulphur oil for spaceheating purposes.

(vi) The 'Commercial B' emission strength is unlikely to be greatly

---

1. For example, a sample study by JURUE (1977b) has shown that housing density in the categories A:B:C has the ratio 2.3:2.2:1.3

different from that of the 'Residential B' category since the building type is usually similar.[1]

The procedure for incorporating these theoretical considerations into a modification of the q_u values was termed an 'iterative apportionment' method. Essentially this involved the following process. The variables in the regression from which the set qu was finally obtained were aggregated into three fundamental types, residential, industrial and commercial.[2] These three fundamental variables were regressed against the National Survey data and it was found that all three variables entered the regression at the 10% significance level, giving the coefficients shown in Table 6.6. It should be noted that it would have therefore been empirically

Table 6.6 Regression Parameters and Coefficients qu for the Aggregate Variables at 10% Significance (for B = 0.30, N = 5)

Regression Parameters	Aggregate Variables		
	Residential	Industrial	Commercial
Coefficient q ($\mu g\ m^{-3}$)	52	127	104
't' value of coefficient	1.97	5.86	3.49
r = 0.784	r.e. = 16.0 $\mu g\ m^{-3}$		K = 36.4 $\mu g\ m^{-3}$

valid to use a model of this form directly, but this was not done because, as shown, there is clear theoretical evidence that considerable differences in emission do in fact occur between the component types of the fundamental variables. Therefore a re-calibration of the full ten coefficients qu was made using the 'fundamental variable' model as a basis. This was done by disaggregating each fundamental activity type in turn and apportioning

1. Often Victorian Streetside-terraced buildings dominate both categories.

2. For example the fundamental residential variable R was given by $R = \sum_{u=1}^{6} r_u$ where u = 1, 6 are the six residential types in Table 6.2.

coefficients, giving three stages of calibration. Firstly the commercial category was disaggregated into its two component activity types, keeping the residential and industrial categories at the aggregate level. A predictive equation was set up based upon the 'fundamental variable' model but with a set of trial coefficients qu for the two commercial categories. The sets of predictions for each combination of trial values of q_u were each regressed against the observed National Survey data to determine model performance for each trial. The trial coefficients for the commercial categories ranged between the q_u values obtained in the empirical regression and those which fitted the theoretical guidelines(for example the empirical values gave a q coefficient for the 'Commercial B' category higher than that for the 'Commercial A' category, whereas the theoretical guideline (v_i) indicates that it should be lower). Through criteria discussed shortly, the most appropriate values of q_u were selected and the second stage of disaggregation was then conducted for the industrial category, keeping the residential category aggregated but introducing the two disaggregated commercial activity types and their newly-selected coefficients. Through the same procedure the most appropriate coefficients for the two industrial activity types were selected and the third stage was conducted for the residential category. Following this cycle the whole procedure was repeated once more, adding refinements to the coefficients. The end result was a set of values of q_u which is given in Table 6.7, where a comparison with the original values obtained through straight forward regression shows that major modifications were only necessary for the three coefficients of the 'Commercial A and B' and the 'Residential C Controlled' categories.

At each stage in the apportionment procedure the choice of the most appropriate values of qu was based on a joint consideration of the theoretical guidelines and the empirical evidence. The empirical evidence was interpreted in terms of the correlation between the observed concentrations

Table 6.7 Apportioned Coefficients qu and Regression Parameters for Simple Regression of Observed to Predicted Concentrations (at 5% Significance)

Coefficients and Parameters	Urban Fabric Activity Types (u = 1,10) and Codes									
	1(RA)	2(RB)	3(RC)	4(RAX)	5(RBX)	6(RCX)	7(IA)	8(IB)	9(CA)	10(RB)
Apportioned Coefficients q_u (ug m^{-3})	52	60	33	38	42	33	145	90	100	80
Regression Parameters	r = 0.783				r.e. = 15.5 ug m^{-3}				K = 44.2 ug m^{-3}	

and those predicted under the assumption of the given coefficients, represented by the regression correlation coefficient r. By plotting the trial coefficient values of a given category against the resulting correlation r (as illustrated in Fig. 6.4) it was possible to detect the

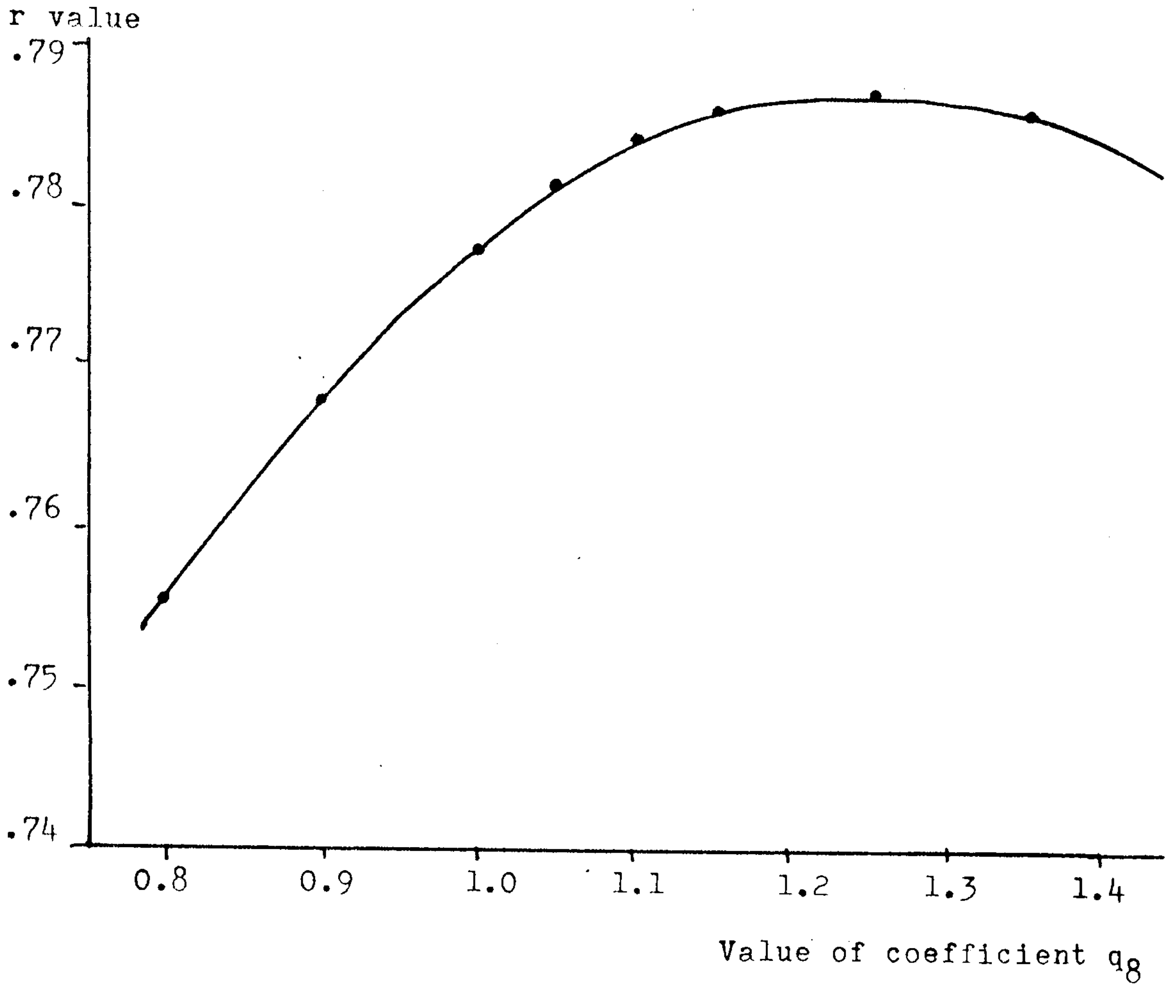

Fig. 6.4 Example of variation in correlation coefficient r with variation in apportioned emission coefficient q_8.

limiting values of the coefficient beyond which the explanatory power of the predictive equation in which they are included becomes severely reduced, but within which the explanatory power is broadly constant. The empirical evidence thus allowed the delimitation of a range of possible coefficient values which were supported empirically; the actual choice of any given qu was made by selecting the coefficient value within this range which accorded most closely with the theoretical guidelines.

It will be noted that because the 'apportionment' method involves changing q_u and G from their optimal ('best empirical fit') values, it is theoretically probable that the diffusion parameters B and N should be changed accordingly since the original 'best fit' values (B = 0.30, N = 5) may no longer be optimal for the revised values of q_u and G. This change was not made however, for a number of reasons. Firstly the fact that modifications were limited to the coefficients of comparatively few r_u variables with relatively low explanatory power implies that the corresponding changes in B and N, if needed at all, will be small. In addition it is evident from Table C.8 in Appendix C.4 that the explanatory power of the model, as assessed by the value of r, is relatively insensitive to the values of B and N, indicating that the diffusive element in the model is of relatively low significance in determining area-mean concentrations of TAE-sized zones in an urban area; indeed the empirical evidence, discussed in section 6.6, is that only some 5% of the between-zone spatial variance in sulphur dioxide concentrations is due to diffusion (this empirical result may be spuriously low if there is a similarity in urban fabric types amongst neighbouring zones, but it was not feasible to test for the extent or significance of this possible effect). Consequently it was concluded that the original 'best fit' values of B and N could be maintained without significantly weakening the model's performance.

The values of qu achieved in the above-described way constitute the best obtainable estimates of the relative emission strengths of the ten urban fabric activity types defined in Table 6.2, given the available empirical and theoretical evidence. These and the resulting background constant G, given in Table 6.7, were therefore the parameter values used in the urban diffusion model.

6.4.4 A Computer Programme for Applying the Urban Diffusion Model to the WMMC

Following the calibration exercise, which formed the major part of the research effort, a computer programme was written which allowed the predicted sulphur dioxide concentration of each TAE zone in the WMMC to be calculated. The central task of the programme was to calculate the set r_u for each individual TAE; the predicted concentration for the particular values of r_u could then be obtained directly by applying the calibrated equation 6.5. From the calibration values given in Table 6.7 it is seen that the final calibration of this equation takes the form:

$$C = 52r_1 + 60r_2 + 33r_3 + 38r_4 + 42r_5 + 33r_6 + 145r_7 + 91r_8 + 100r_9 + 90r_{10} + 44 \qquad 6.7$$

where r_u, u = 1,10 describe the proportional contributions from the urban fabric activity types defined in Table 6.2, given the calibrated diffusion parameters B = 0.30 and N = 5.

The computer programme was designed specially for this study and was written in UAFORTRAN for the Aston University ICL 1904S computer; a copy is presented in Appendix C.3. The programme 'reads' an urban fabric data bank input into a three-dimensional array with the TAE grid for the WMMC comprising two dimensions of 'cells' describing the proportions of each TAE covered by the ten urban fabric activity types u(u=1,10). The computer then calculates r_u for each individual TAE by applying the same aggregation and diffusion - function process as described in Table 6.3, resulting in a three-dimensional array of r_u values. This is converted to a two-dimensional array of predicted concentrations by applying equation 6.7; thus a spatially comprehensive set of predicted concentrations is achieved from the application of the calibrated urban diffusion model to each individual TAE in the WMMC. As seen in Section 6.5 below, a cartographical representation of the resulting pattern was achieved through manual isolining.

6.4.5 Validity and Accuracy of the Urban Diffusion Model

An assessment of some of the factors affecting the validity and accuracy of the empirically-derived model has already been given in section 6.4.3. To a certain extent the introduction of theoretical factors into the calibration procedure strengthened the validity and reliability of the resulting model; however there are additional points that must be considered.

It is to be expected that the model predictions will be most closely correlated with the concentrations observed at the centres of zones. This is not because the model predicts concentrations for central receptor points like the models based upon Gaussian theory; on the contrary it is, as stated, allied to the 'box model' theory and predicts an assumedly homogeneous concentration for the whole area of a given receptor zone. However the model theory involves the assumption of homogeneous zone emission - in other words the ascribing of a uniform emissions 'identity' to the whole area of a given zone. Since differences or 'trends' in emission strength occur between zones which reflect an underlying continuum in conditions - certainly in the case of actual concentrations - the identity ascribed to the whole zone becomes decreasingly appropriate as one approaches boundaries with neighbouring zones. Thus for points at the zone centre, conditions most closely represent the assumptions of the model,[1] and it is here that the highest correlation between predicted and observed concentrations should be expected.

In Table 6.7 it was stated that the model possessed a correlation coefficient $r = 0.783$ and a residual error $r.e. = 15.5\ \mu g\ m^{-3}$. In assessing this correlation between predicted and observed concentrations (which

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1. This is a general feature wherever spatially continuous data are approximated into zones.

forms the basis of the regression analysis methods previously described) it should therefore be noted that the correlation coefficient obtained describes the degree of association between a predicted area mean concentration for a given zone and an observed concentration at one particular site within the zone; moreover since the National Survey sites were located independently of the TAE grid system of this research, the sites are located randomly within the zones and not at zone centres. Ideally the correlation should be derived between the model's predicted area mean concentration and an observed area mean concentration, if the correlation coefficient is to be used as a measure of the model's explanatory power. Since only one site was available in any single TAE it was not possible to obtain observed area-means, unlike the ambient noise study; indeed it was not even possible to estimate the within-TAE variance of observed point-concentrations.

Two points therefore emerge in assessing the values of the correlation coefficient and the residual error. Firstly, the correlation coefficient is lower (and the associated error higher) than would be the case if the dependent variable consisted of observed area mean concentrations, as it should for a valid test of the model's performance to be made; this is because of the additional random statistical variation that is included in the dependent variable data, owing to within-zone variance in concentrations. Secondly, if the dependent variable had been observed at zone centres, a higher correlation (and lower error) would be expected; consequently if the model was used to predict point concentrations located at zone centres, its accuracy would be somewhat higher than that shown in the regressions. This is of interest in the use of the model as an alternative mapping method to the TAE methodology (see section 6.5).

Both these points imply that the calculated values of the residual error r.e. are higher than would be obtained if a valid test of the model's performance could be made. Offsetting this however is the fact that parameters have been obtained from data upon which the model itself was formulated and calibrated; thus they are not independent estimates of the model's performance. Independent estimates could only be made upon data from further, independent sample sites; these were not available and so it was not possible to determine the extent to which this affected the robustness of the model.

Despite their questionable degree of validity and accuracy the values of r and r.e. obtained from the regression were necessarily used to evaluate the model's performance because no better data were available. Standard procedures were used (see Appendix C.4) to draw up the 95% confidence intervals of the model. These are illustrated in Fig. 6.5 for the simple linear regression of observed to predicted concentrations, and are derived from the residual error r.e. = 15.5 ug m^{-3}. The outer pair describe the confidence in predicting the concentration of any point in any given TAE zone; the inner pair describe the confidence in predicting the mean concentration of all points in all TAEs with a given value for the independent variables. As discussed in connection with the hypothesis test in section 6.3.2, the parameter which truly represents the accuracy[1] of the urban diffusion model, describing the confidence in predicting the mean concentration of all points in a given TAE, will lie some way in between these values, being higher than that of the inner pair of intervals due to between-zone variability. It should be noted that these prediction errors, although comparatively large, do not invalidate the hypothesis - indeed as stated in section 6.3.2, they result in a stronger F-test.

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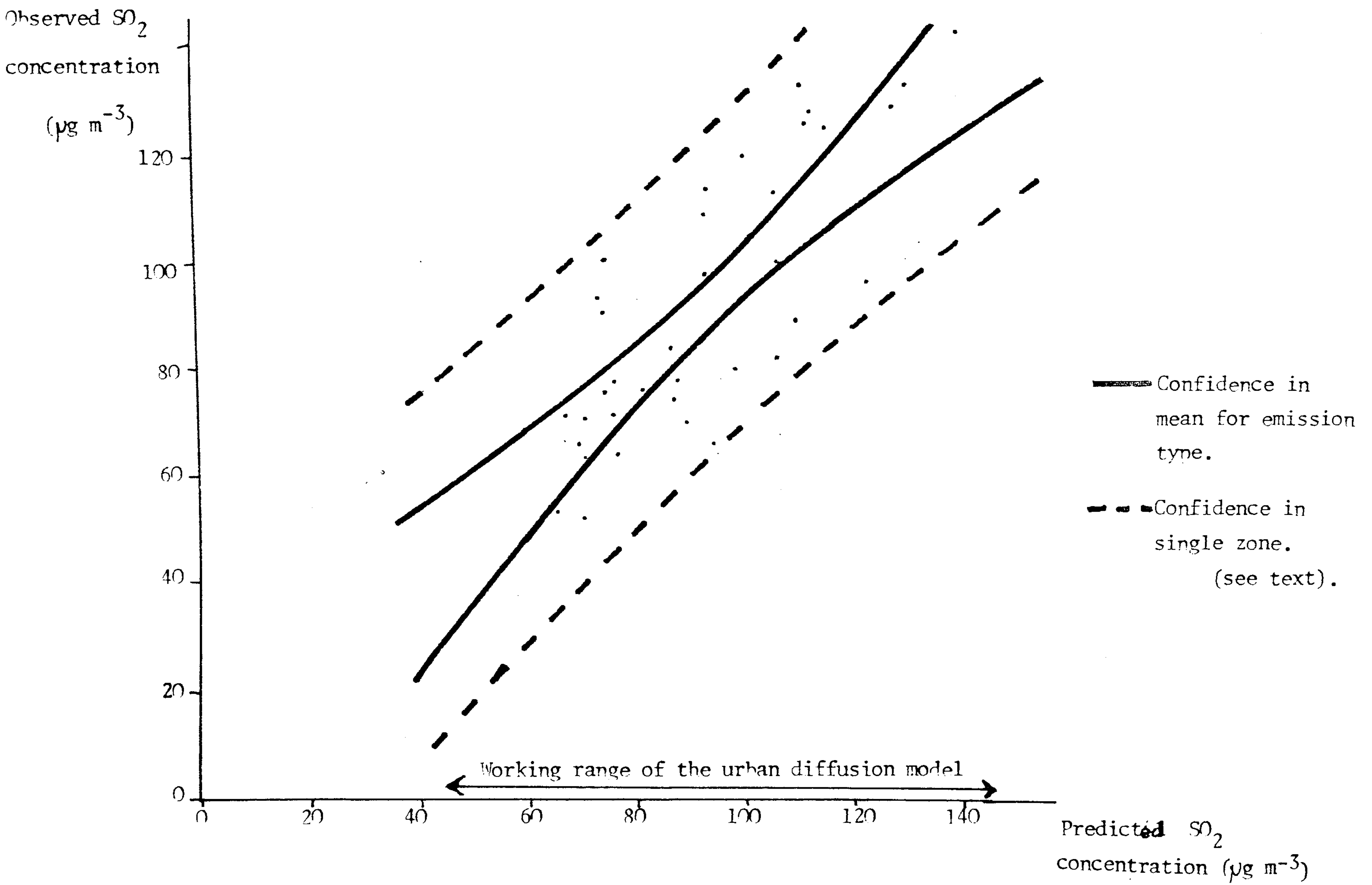
1. The confidence intervals may be applied to the full working range of the model since the sample frame of observed concentrations was good (see Appendix C.4).

Fig. 6.5 95% confidence bands for the sulphur dioxide urban diffusion model



This section has treated in considerable depth the nature of the urban diffusion model and the research method adopted to test and validate it. This is seen to be necessary in view of the fact that the model itself represents an alternative mapping method to the TAE methodology, and represents the most appropriate example of a well-established set of air pollution modelling methods. Broadly, its advantages over the TAE methodology lie in the greater accuracy and spatial precision that it affords. This is due particularly to the fact that the model treats each TAE zone individually (instead of aggregating and classifying zones with respect to the TAE typology), and disaggregates and quantifies the component urban activity types. In addition, dispersive factors are allowed, and in section 6.6 it will be seen that an estimated 5% of the total variance between zones over the study area is due to diffusion from one zone to another. The model is also versatile in representational terms since, as section 6.5 shows, it may be used for both isopleth and choropleth mapping displays. Its disadvantages as against the TAE methodology are, paradoxically, due to the very analytical complexity that provides for the improved accuracy and precision - a fact that underlines the importance of the particular requirements of the operational policy context in determining what is the appropriate analytical approach. In a study solely concerned with the detailed knowledge of the air pollution pattern, the urban diffusion model would probably be the better method. In contexts however where general 'state of the environment' and 'baseline' conditions are of interest, especially where a range of environmental attributes are to be compared, it is argued in section 6.6 that the TAE methodology is superior; it gives a simple method for classifying the typical pollution levels of certain 'standard' types of area for which other environmental and non-environmental data may be obtained, thus allowing comparisons, aggregations, and the mapping of conditions, to be carried out with respect to a common framework of area types (see Chapter 9).

6.5 MAPPING METHODOLOGIES: THE TAE AND URBAN DIFFUSION MODEL METHODS

This section describes the two alternative methods available for mapping the pattern of sulphur dioxide concentrations over the WMMC, the first involving the TAE methodology and the second the results of the urban diffusion model computer predictions. The TAE prediction model was applied as a mapping method through an identical grouping procedure to that used in the ambient noise study. The urban diffusion model was used to obtain both isopleth and choropleth maps through 'interval' grouping procedures; the resulting three maps are compared and contrasted.

6.5.1 The TAE Mapping Method

As in the ambient noise study, TAE types were grouped into the prescribed number of five categories through a 'natural grouping' process allied with consideration of discontinuities in the urban fabric characteristics of the TAE types when they are listed on a scale of mean predicted sulphur dioxide concentrations. This listing is given in Fig. 6.6 and, as was also found in the ambient noise study, it is evident that although the hypothesis test showed that the TAE samples did not all come from the same population, it was not true to say that the TAE type populations were all significantly different each from another. This is seen in Fig. 6.6 by reference to the 95% confidence 'significant gap' values; since no precise knowledge of the error of estimate of the TAE prediction model was available it was necessary to calculate the 'significant gap' values associated with the two (highest and lowest) estimates of the error as given in section 6.3.3. These were found[1] to be 13.9 and 24.7 $\mu g\ m^{-3}$ and are shown in Fig. 6.6.

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1. For a standard error of estimate σ and with 3 samples per TAE type, the 95% confidence 'significant gap' D_{95} between the means is given by $D_{95} = t_{95}\sqrt{\frac{2\sigma^2}{3}}$

Fig. 6.6 Distribution of predicted TAF type area-mean SO_2 concentrations, related to statistically significant 'gaps'.

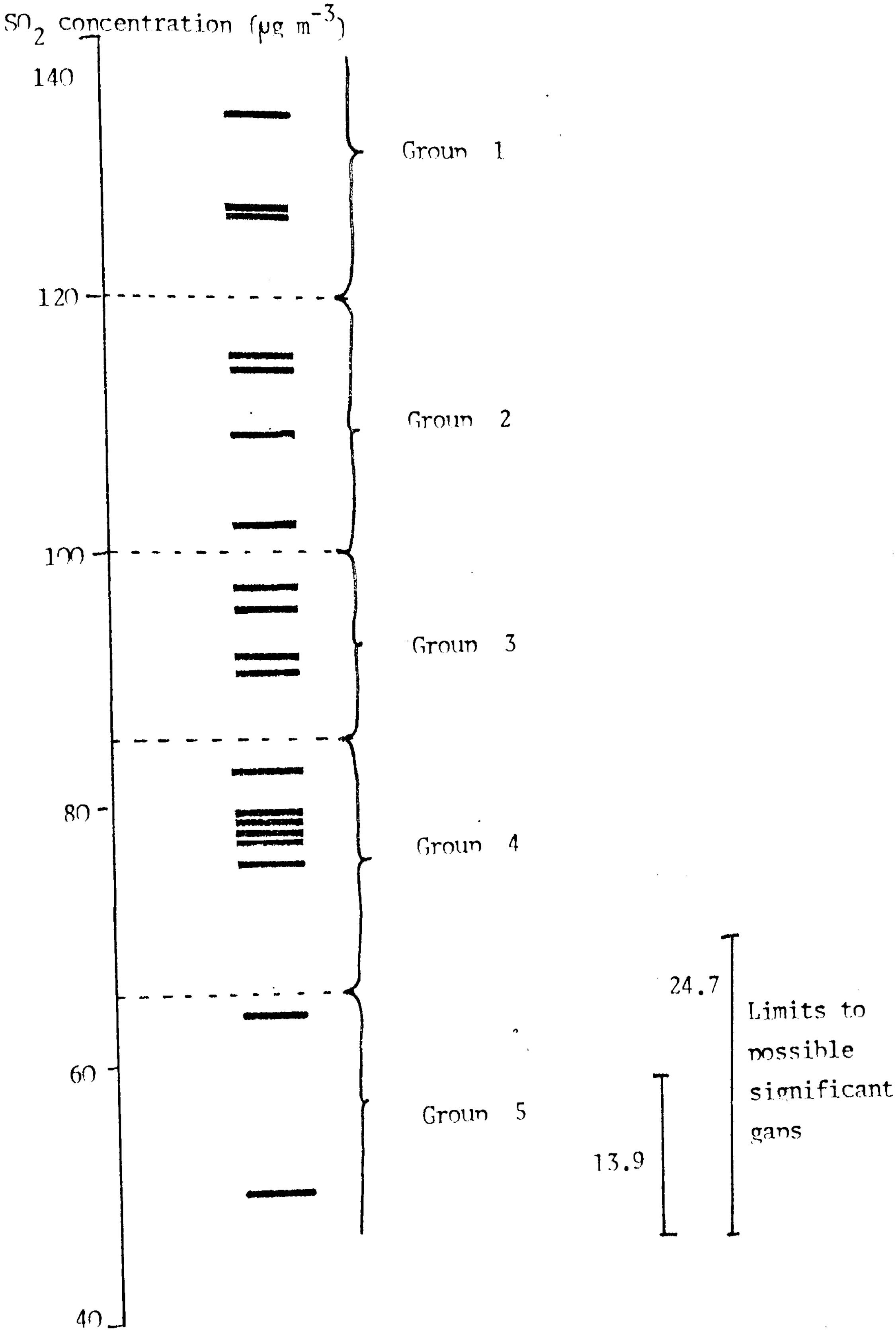


Table 6.8 Grouping of TAEs: Predicted Concentrations and Description of Each Group

Group	TAE Type	Predicted Concentration ($ug\ m^{-3}$)	Group intervals ($ug\ m^{-3}$)	% WMMC area in each group
1	6A Commercial/Ind/Dense 1A Industrial/Dense 2A Commercial/Dense	134 126 126	above 120	3.5
3	4A Res/Ind/Dense 1B Industrial/Medium 6B Ind/Comm/Medium 4B Res/Ind/Medium	115 114 109 103	100-120	16.1
3	5A Res/Comm/Dense 5B Res/Comm/Medium 0B Residential/Medium 0A Residential/Dense	97 95 91 90	85-100	18.1
4	7B Res/OS/Medium 5C Res/Comm/Sparse 8B Ind/OS/Medium 7A Res/OS/Dense 8C Ind/OS/Sparse 0C Residential/Sparse	82 79 79 78 77 75	70-85	30.7
5	7C Res/OS/Sparse 3C Open Space/Sparse	63 54	below 70	31.6

Table 6.8 shows the TAE types ordered in terms of their predicted concentrations, and the groupings that were achieved. In this and in Fig. 6.6 the gaps between TAE types 2A and 4A, 4B and 5A, 0A and 7B, and 0C and 7C, are clearly evident, although it is equally clear that in neither case is the gap large enough to be of itself statistically significant. These gaps were taken to be indicative of possible 'natural' breaks in the metric scale, and since it is also evident that a substantial urban fabric consistency exists within the five groups so delimited, and moreover the group intervals so defined are as wide as or wider than the significant gap (this criterion for grouping is discussed in detail in Chapter 5.5.1) it was decided to adopt the five groups defined by these gaps.

This grouping results in a distribution of WMMC land area amongst the groups which is very similar to that shown in Table 5.8 for the ambient noise grouping; to some extent this is due to the fact that the urban fabric composition of the two grouping sets is similar, a point discussed further in Chapter 8. In the absence of absolute criteria for grouping this is advantageous in contexts such as this where the values and pattern of one indicator are compared with those of another upon a 'common normalised scaling system' such as the 'five groups' approach, since relative criteria of comparison are set up on the basis of a standard size of the area affected. For example if for each indicator 'group 1' describes the conditions of the worst 3% or so of the total WMMC land area, then the environmental conditions associated with group 1 areas, and their spatial location, may be compared between indicators with respect to the common areal baseline. In the context of mapping this removes the capacity for showing whether the conditions described by one indicator are <u>in general</u> 'worse' or 'better' over the study area than those of another, since conditions have become normalised with respect to their spatial cumulative frequency distributions within the study area. However, not only is there a compensating increase in the informative value of the spatial <u>pattern</u>

resulting from the existence of a common areal baseline for each group, but in addition the complex methodological issues surrounding the relative weighting of indicators, which confront any attempt to compare the absolute values of different indicators, are avoided (the thesis investigates the weighting issue further in Chapters 7 and 8).

A TAE choropleth map showing the pattern of the five categories of sulphur dioxide conditions resulting from the grouping of TAE types as defined in Table 6.8 was achieved, using the same procedure as that described in the ambient noise study (Chapter 5.5.1). The resulting map is shown in Fig. 6.7, and again 'stress' and 'high stress' areas corresponding to groups 2 and 1 respectively are shown independently in Fig. 6.8 in order that the display may give emphasis to the location of particular 'problem' areas. These Figures should be compared with the equivalent maps of ambient noise conditions (Figs. 5.10 and 5.11), and with the 'overlay' map of the most prominent land use types. The similarity in pattern between the ambient noise and sulphur dioxide maps is strongly evident and the prominent association of the 'stress' and 'high stress' areas of both indicators with the commercial centres and industrial zones should be noted. Considering the maps and groupings in more detail it is seen that group 1 contains all the major industrial and commercial areas, focussing upon Birmingham but also including Coventry and the 'Black Country' towns. Group 2 covers the remaining industrial areas except for those that are mixed with open space (which aids dispersion); thus group 2 is substantially evident to the North and East of Birmingham and in the Northern half of the 'Black Country' especially in the band through Smethwick and West Bromwich to Wolverhampton and Walsall. Group 3 is largely the more densely built-up residential sector containing small shopping centres evident throughout the conurbation and around Coventry; group 4 is of lower density with residential areas on sparser road networks and it also includes the industrial areas which are mixed with open space; the latter fall in the urban periphery of the Black Country while

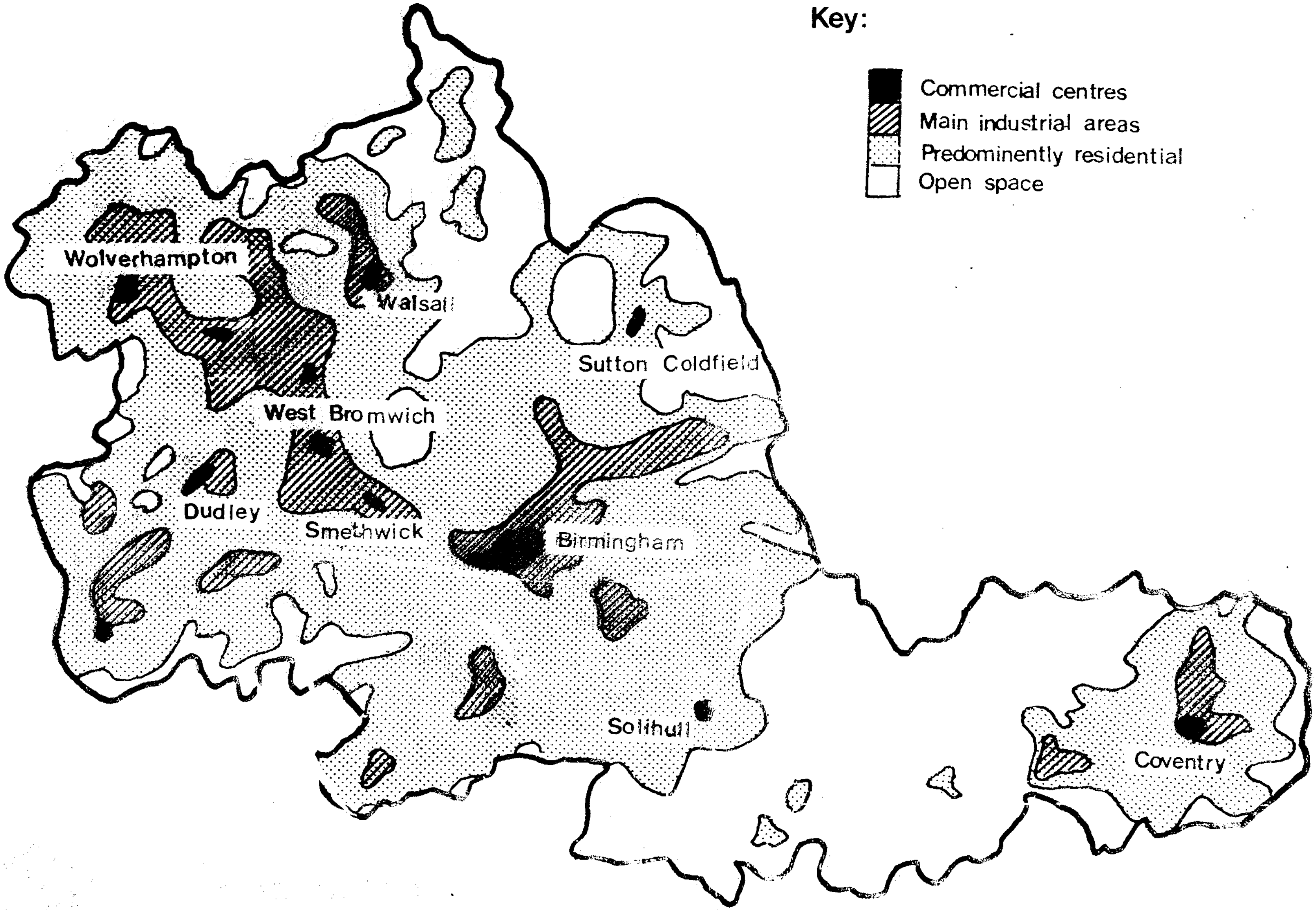


Fig. 6.7 Map showing the predicted sulphur dioxide conditions in the WMMC (obtained from the TAE model)

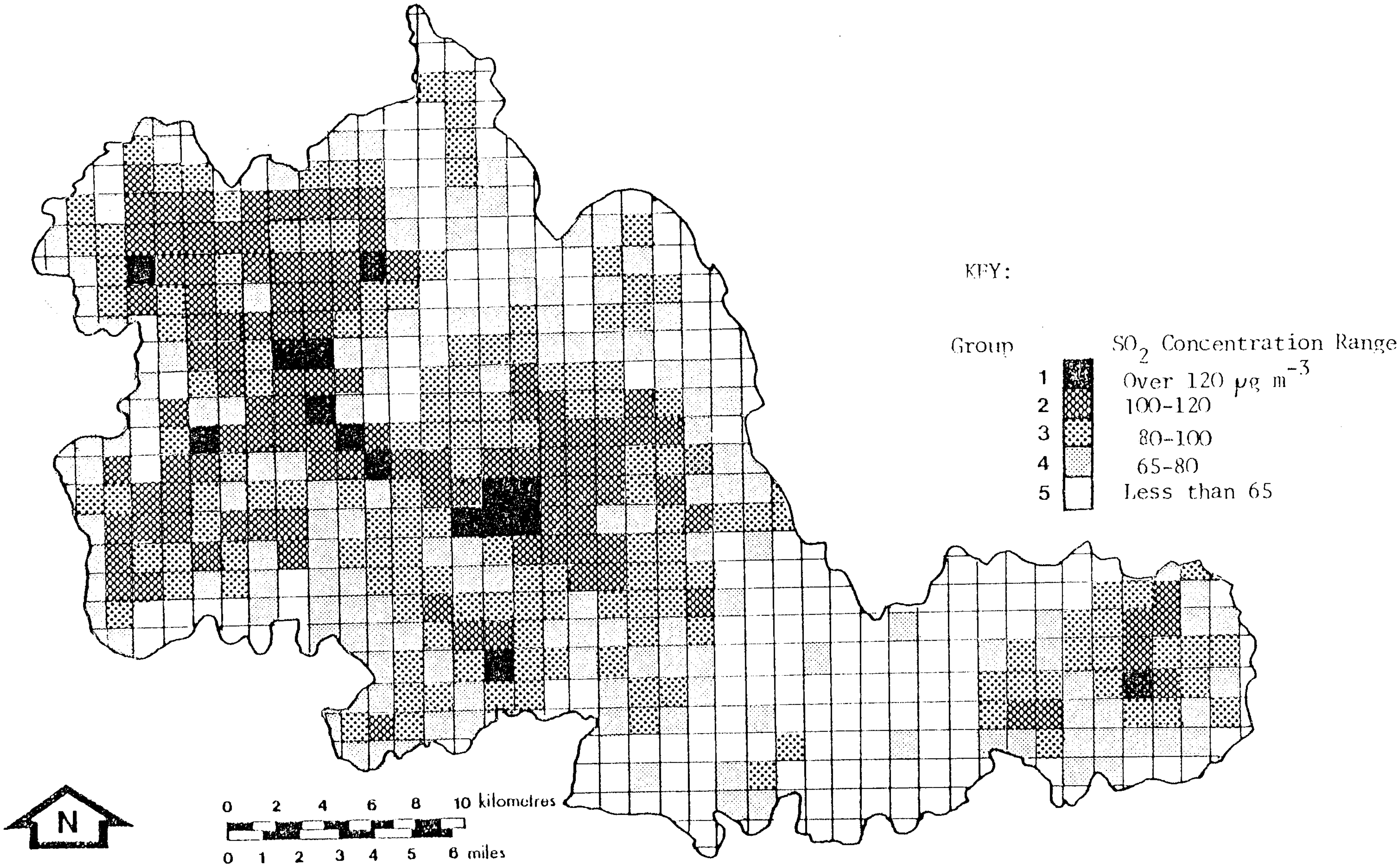


Fig. 6.7 Map showing the predicted sulphur dioxide conditions in the WMMC (obtained from the TAF model)

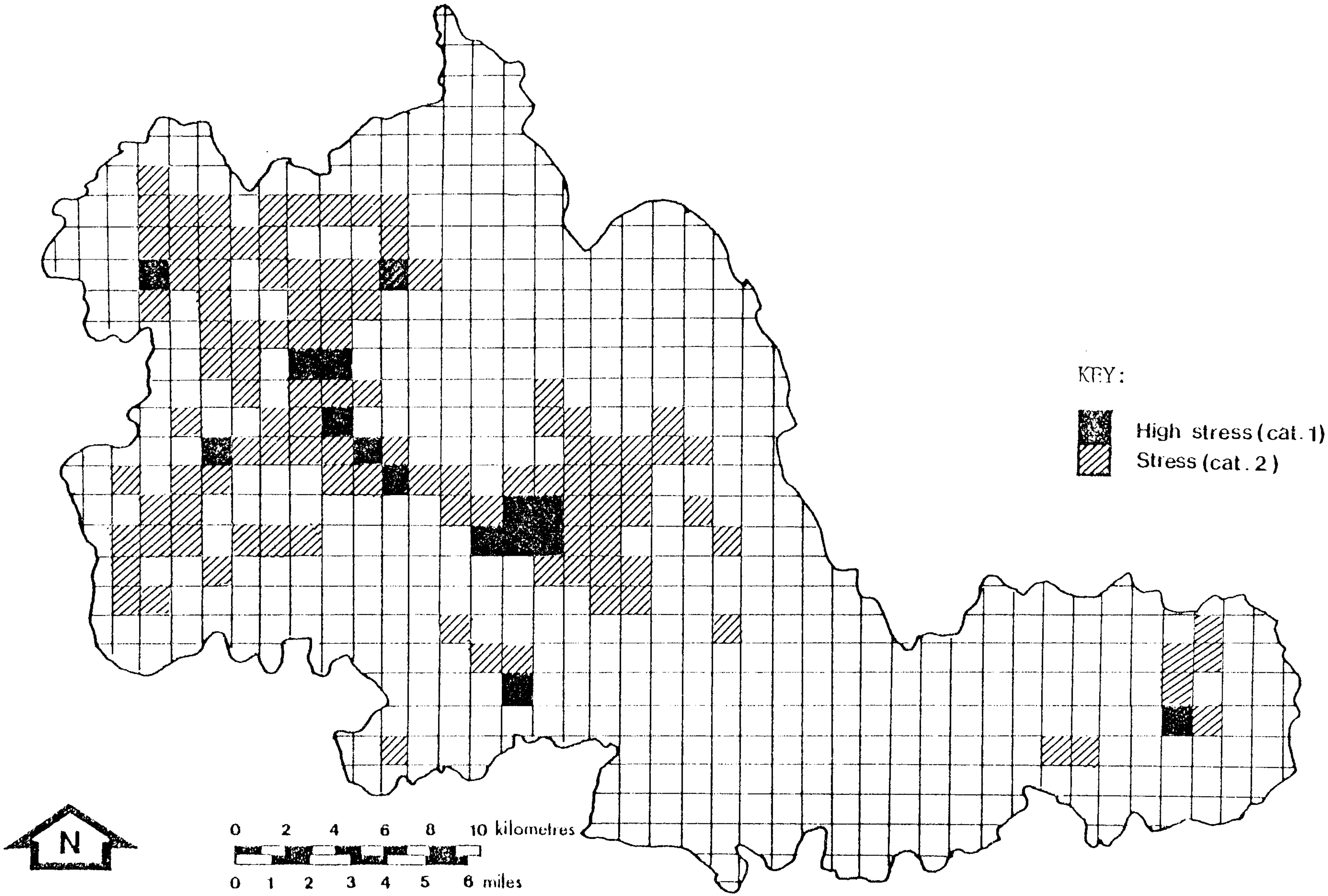


Fig. 6.8 Map showing 'stress' and 'high stress' areas for sulphur dioxide (obtained from the TAE model)

the former are especially prevalent to the south and west of Birmingham. Group 5 consists of rural areas and semi-rural residential areas where local sources of sulphur dioxide are few and far between.

The sulphur dioxide levels themselves do not appear to be untypical of UK conurbations, although comparisons are difficult to establish because the National Survey isoline maps (see discussion in 6.5.2 below) are the only source of contemporary measurements. The concentrations show the effects of a continuing trend towards cleaner air (see section 6.6.1). However the World Health Authority have recommended that Winter mean concentrations above 90 $\mu g\ m^{-3}$ are undesirable from a health point of view (WHO 1972), and this indicates that a substantial proportion of the WMMC land area (some 25%, as seen from the cumulative frequency distribution in Fig. 6.3) experiences pollution levels that are unsatisfactorily high. The spatial distribution of areas with these conditions may be determined from Fig. 6.8 since the WHO criterion covers approximately the 'stress' and 'high stress' groups 2 and 1.

6.5.2 The Urban Diffusion Model as a Mapping Method

Section 6.5 has described the method through which computer predictions of mean sulphur dioxide concentrations were obtained for each TAE using the urban diffusion model. Two methods were available for mapping this data: approximation zoning using the TAE grid as the choropleth base, and manual (interpolation) isolining. This section discusses the results of using both approaches, and compares them with the results of the TAE methodology.

In accordance with the general principles already established, the choropleth method requires the predicted concentrations to be grouped into intervals in order that the display of data may be simple and readily intelligable. Without the aggregation of TAEs into types and the established association between TAE types and mean concentrations each TAE must be treated as a separate data item, and grouping is possible only through sectioning the data measurement scale. A preference for natural grouping has been expressed, but the frequency and cumulative frequency distributions shown in Figs. 6.9(a) and (b) indicate that no natural discontinuities are evident. It was decided to use simple interval grouping, applying the same scale intervals as were used in the TAE grouping in order to enhance comparability. The resulting frequency distribution of data items across the five groups so defined was found to be very similar to that given in the grouping of TAEs, as shown in Table 6.9; this is also seen by comparing the more detailed distributions given in Fig. 6.9(b) and Fig. 6.3. The close comparability of the distributions implies that at this level of aggregation the approximations intrinsic to the TAE methodology do not lead to substantial or systematic error.

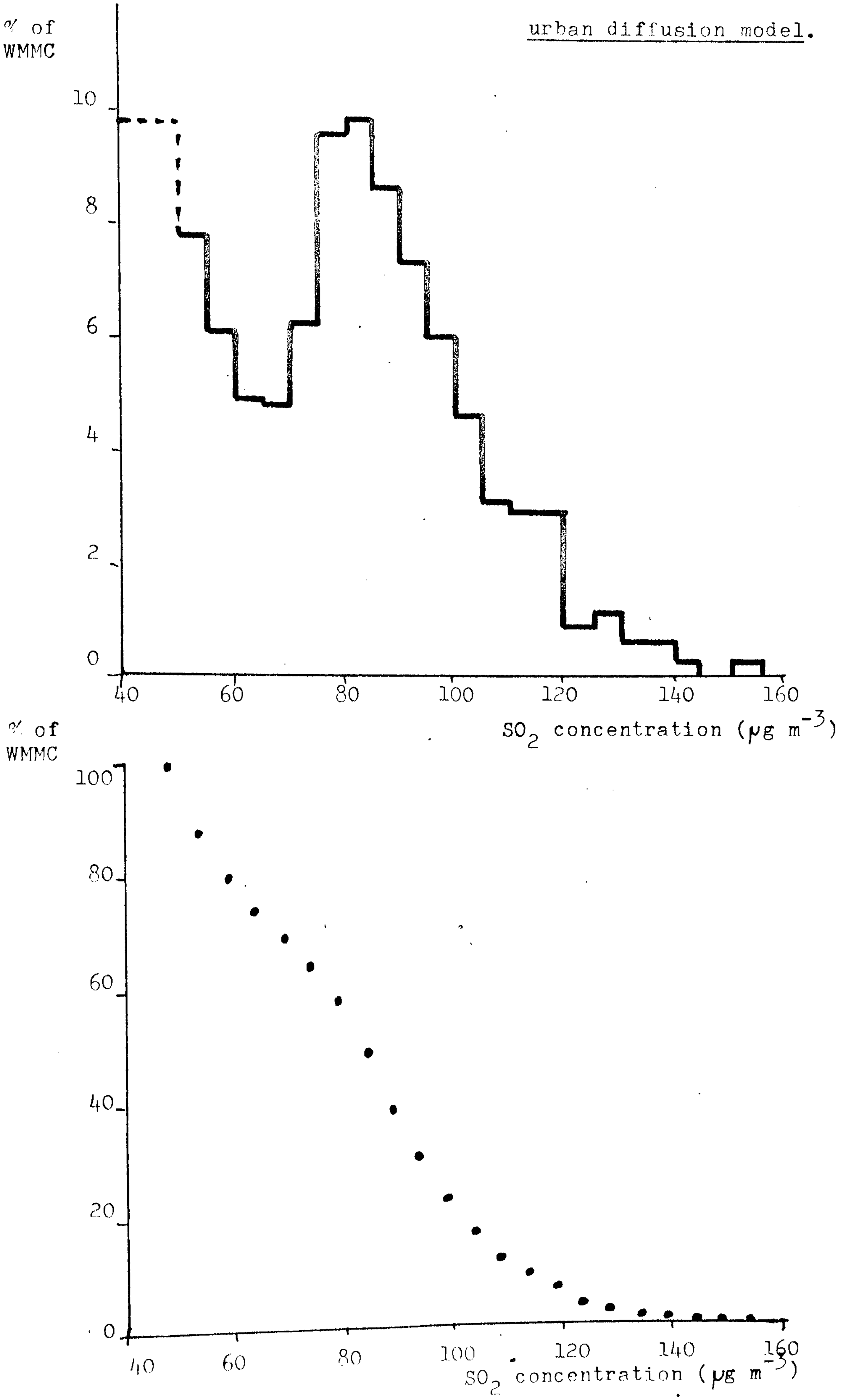
When translated into spatial pattern, a similar comparability is observed between the results of the two methods. Figs. 6.10 and 6.11 show the equivalent patterns for all five groups and the 'stress' groups

Table 6.9 Group Intervals, and Comparison of the Area Distributions Predicted from the TAE and Urban Diffusion Model Methods

Group	Group intervals ($\mu g\ m^{-3}$)	% of WMMC Area in Each Group	
		TAE Method	Urban Diffusion Model
1	120 and above	3.5	3.2
2	100 - 120	16.1	13.4
3	80 - 100	18.1	22.0
4	65 - 80	30.7	25.7
5	65 and below	31.8	35.7

respectively, and should be compared with Figs. 6.7 and 6.8 respectively. Broadly similar patterns are evident in each case, but the maps resulting from the urban diffusion model show a 'smoother' continuum of pattern; this is what would be expected of a method which treats each TAE individually and does not involve the classification (i.e. aggregation) of area units into

Fig. 6.9 Frequency and cumulative frequency distributions of sulphur dioxide concentrations in the WMMC, obtained from the urban diffusion model.



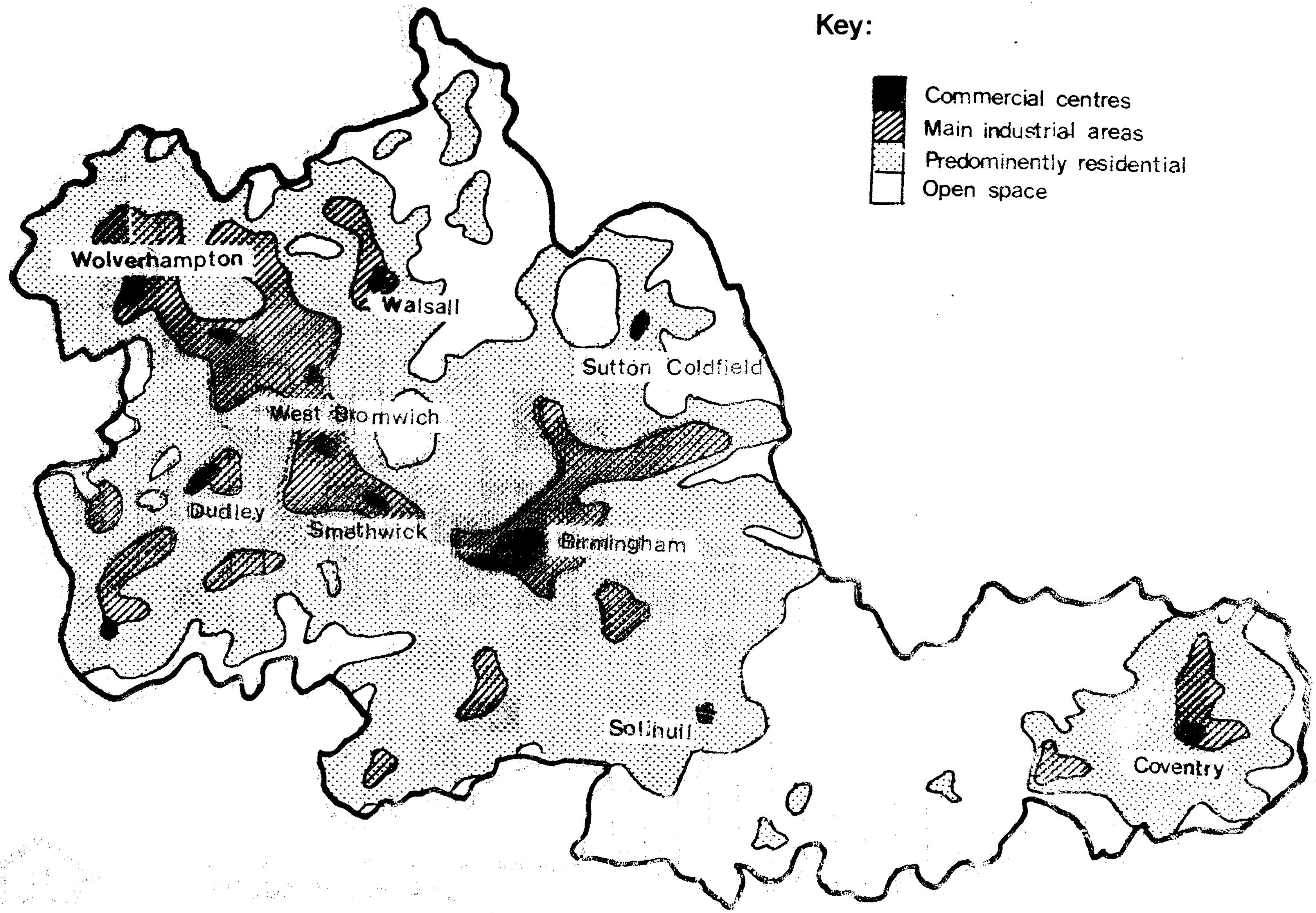


Fig 6.10 Map showing the predicted sulphur dioxide conditions in the WMC (obtained from the urban diffusion model)

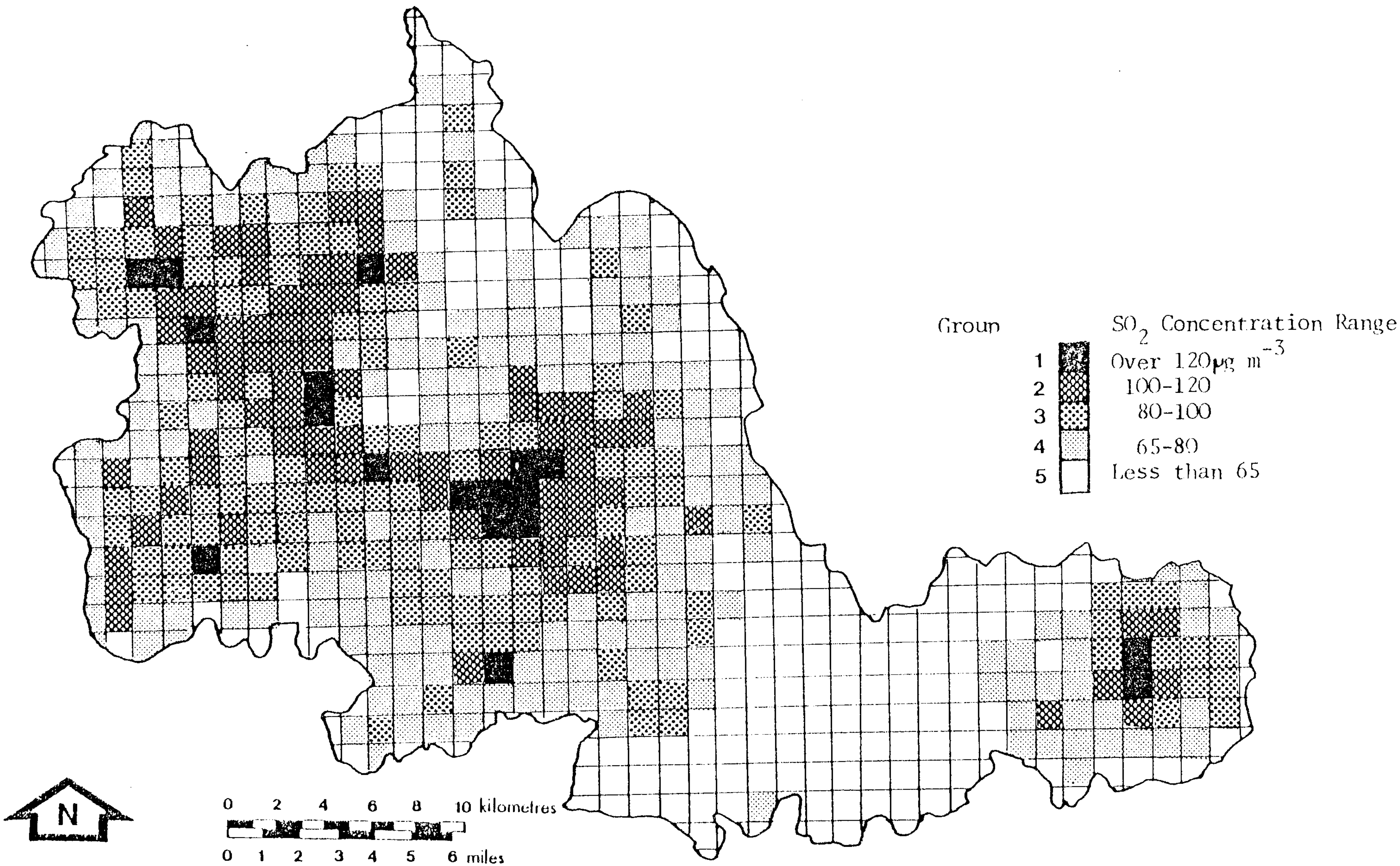


Fig 6.10 Map showing the predicted sulphur dioxide conditions in the WMC (obtained from the urban diffusion model)

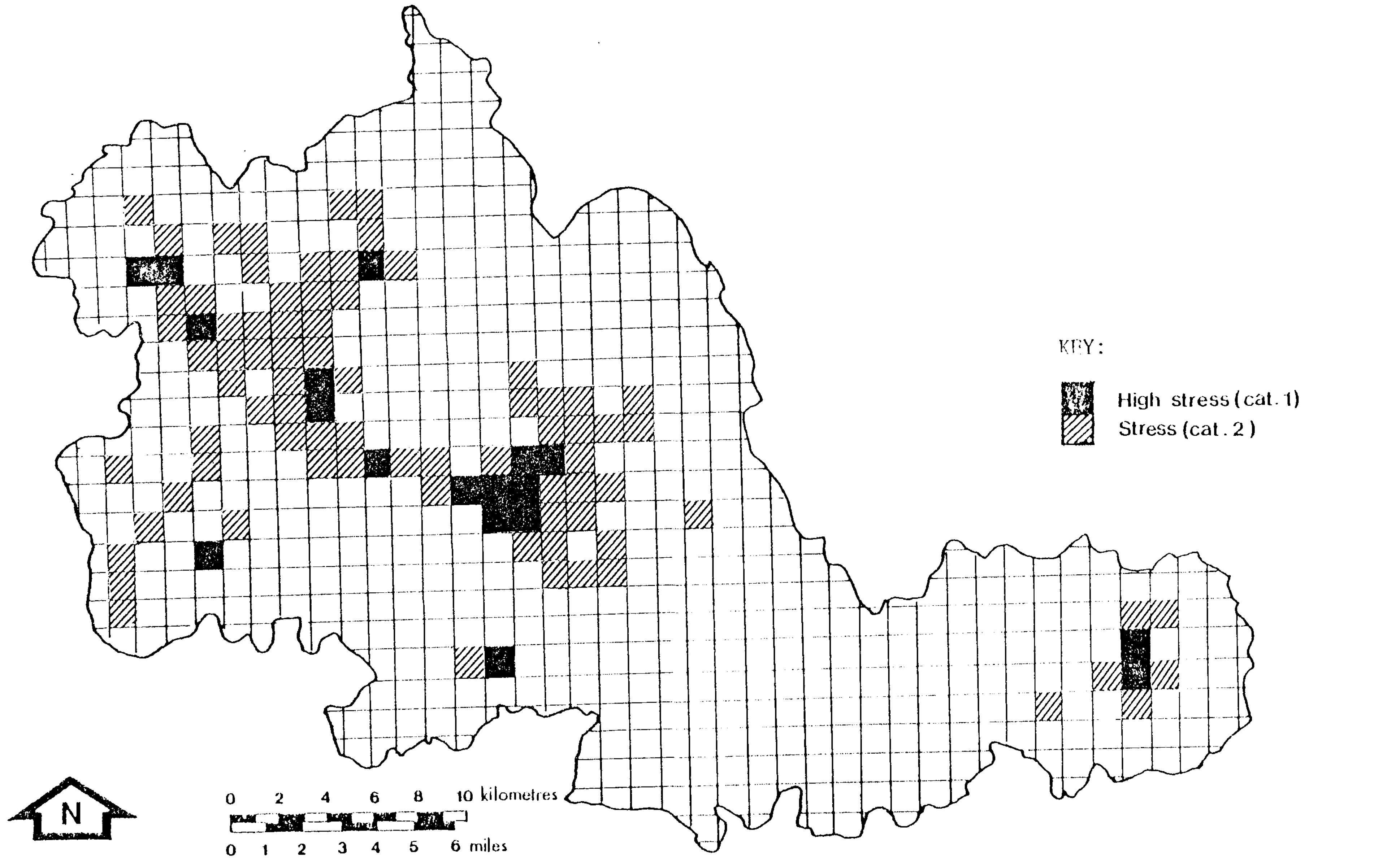


Fig. 6.11 Map showing the 'stress' and 'high stress' areas for SO_2 (obtained from the urban diffusion model)

TAE types.

Offsetting this advantage of greater mapping accuracy however is the fact that the conditions of the mapped isoline 'groups' are not directly related to urban fabric types and are therefore somewhat less useful in terms of describing the general conditions of types of area. Thus it is not possible to discuss in general terms the urban fabric characteristics of the spatial pattern, unlike the approach taken in the TAE mapping context.[1] These points are examined further below and in section 6.6.

An isopleth map was also obtained from the urban diffusion model predictions. The map, shown in Fig. 6.12, was derived through the manual isolining technique with the predicted concentrations taken as point receptor values located at the zone centres. Strictly this is invalid since the 'box model' principle has been seen to result in 'area mean' predictions, but it was also established (section 6.4.5) that the association between these and point-receptor concentrations is strongest for points at the zone centre. The isopleths were drawn freehand through the matrix of point values; theoretically the computational techniques of trend surface analysis or SYMAP could have been used but these were not seen to be necessary for such a spatially complete data set. The interval values chosen for the isolines corresponded to World Health Authority standards, which allow for a direct comparison between this map and that obtained by the Warren Spring Laboratory (see section 6.6.1). No particular advantage would have been gained from using the same interval values as were applied in the choropleth-based grouping procedure since the displays are not equivalent. They may however be compared, and indeed Fig. 6.12

1. But it should be noted that within the calibration of the urban diffusion model itself, there is an explicit analysis of the emission characteristics of urban fabric activity types which is more detailed than the analysis made in the TAE methodology.

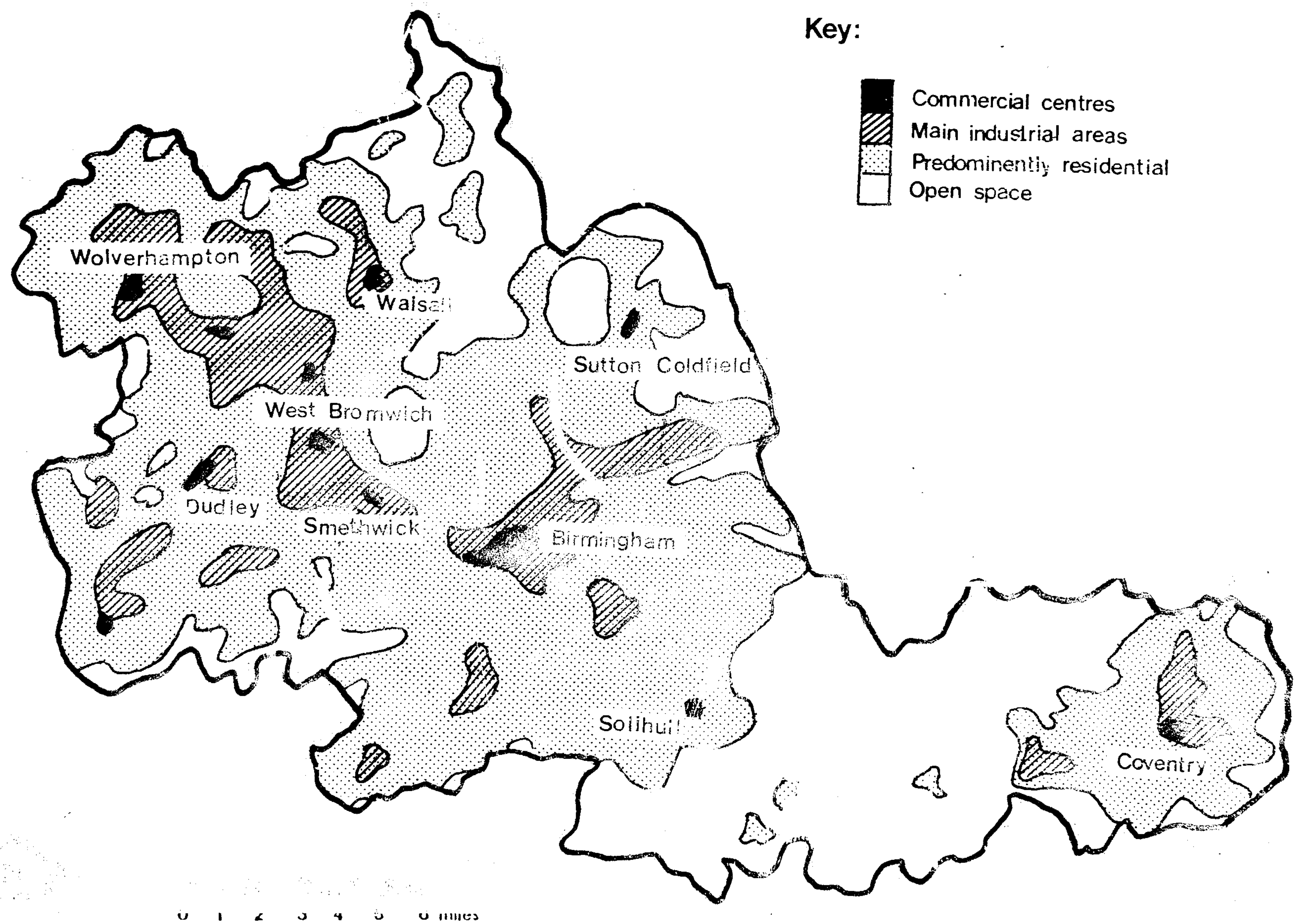


Fig. 6.12 Isopleth map of predicted sulphur dioxide concentrations (1975/6);urban diffusion model data.

Fig. 6.12 Isopleth map of predicted sulphur dioxide concentrations (1975/6); urban diffusion model data.

should be compared with Figs. 6.10 and 6.7 in order to note the similarity in pattern between the maps. The isopleth map naturally asserts the greatest degree of spatial precision since it is not constrained to the spatial 'resolution level' of the TAE zone, and its close association with the isoline land use map as shown by the overlay is interesting (see section 6.6.2). Within the planning context however it is less useful since urban fabric data and predicted concentrations are not associated in a direct and simple way which allows aggregation, analysis and comparison with other indicators, particularly those expressed zonally like ambient noise; the relationship may only be assessed visually. It is in this respect that the TAE methodology, with its standard area units and grouping method allied with an urban fabric classification, has its greatest advantages over alternative mapping methods. These are therefore important characteristics of the TAE methodology since they govern the principal arguments in favour of its adoption in contexts such as those covered by this research. A more detailed discussion is therefore made in the appraisal of the methodology in Chapter 9.

This section has compared the two possible methods of obtaining sulphur dioxide maps, and the three maps produced. The main conclusions are summarised in the following section.

6.6 COMPARISONS AND CONCLUSIONS

This section completes the case study of sulphur dioxide conditions in the WMMC by comparing the results of the research with those of other studies, and by making conclusions about the strengths and weaknesses of the TAE methodology, and comparisons between it and the urban diffusion model mapping method.

6.6.1 Comparison of Results with Other Studies

In the case of sulphur dioxide studies the TAE methodology is apparently unique in its technique of associating types of area with typical pollution levels and so it is not possible to make direct comparisons with the results of other 'category' prediction models as was done in the ambient noise study (Chapter 5.6.1). The sulphur dioxide air pollution pattern over the WMMC has however been depicted in isopleth form as a result of studies by the Warren Spring Laboratory (DoE 1976), and this pattern may be compared with those achieved by the mapping methods described above.

The Warren Spring Laboratory isopleth map is shown in Fig. 6.13, and is best compared with the urban diffusion model isopleth map since this was drawn to the same isopleth intervals. It will be remembered that the WSL method involves a combination of measurement-based and 'mental modelling' prediction techniques (see Section 6.2.3) and the map shown in Fig. 6.13 is for the Winter mean values of the year 1972/3. When compared with the predictions of this research for the winter 1975/6 (Fig. 6.12) the general decrease in concentrations over this period is evident, while the spatial pattern itself is broadly similar. The only significant discrepancy is in the South West of the County, around Dudley. As seen by comparison with the land use map 'overlay', the WSL map does not show any particular effect in terms of higher concentrations associated with this urban and industrial centre and it is argued that the urban diffusion model predictions are the more accurate. The point is supplemented by the observation that the WSL map attempts less spatial precision in the display, a not unexpected finding in view of the fact that the methodology of the research described in this thesis is much more precise and quantitative.

Without the ability to compare quantitatively the emissions characteristics of the urban fabric types the only available comparative tests are those concerning general model performance. Table 6.10 shows the percentage explanations of observed spatial variances in this research and two other large scale urban studies, in each case involving both dispersion and

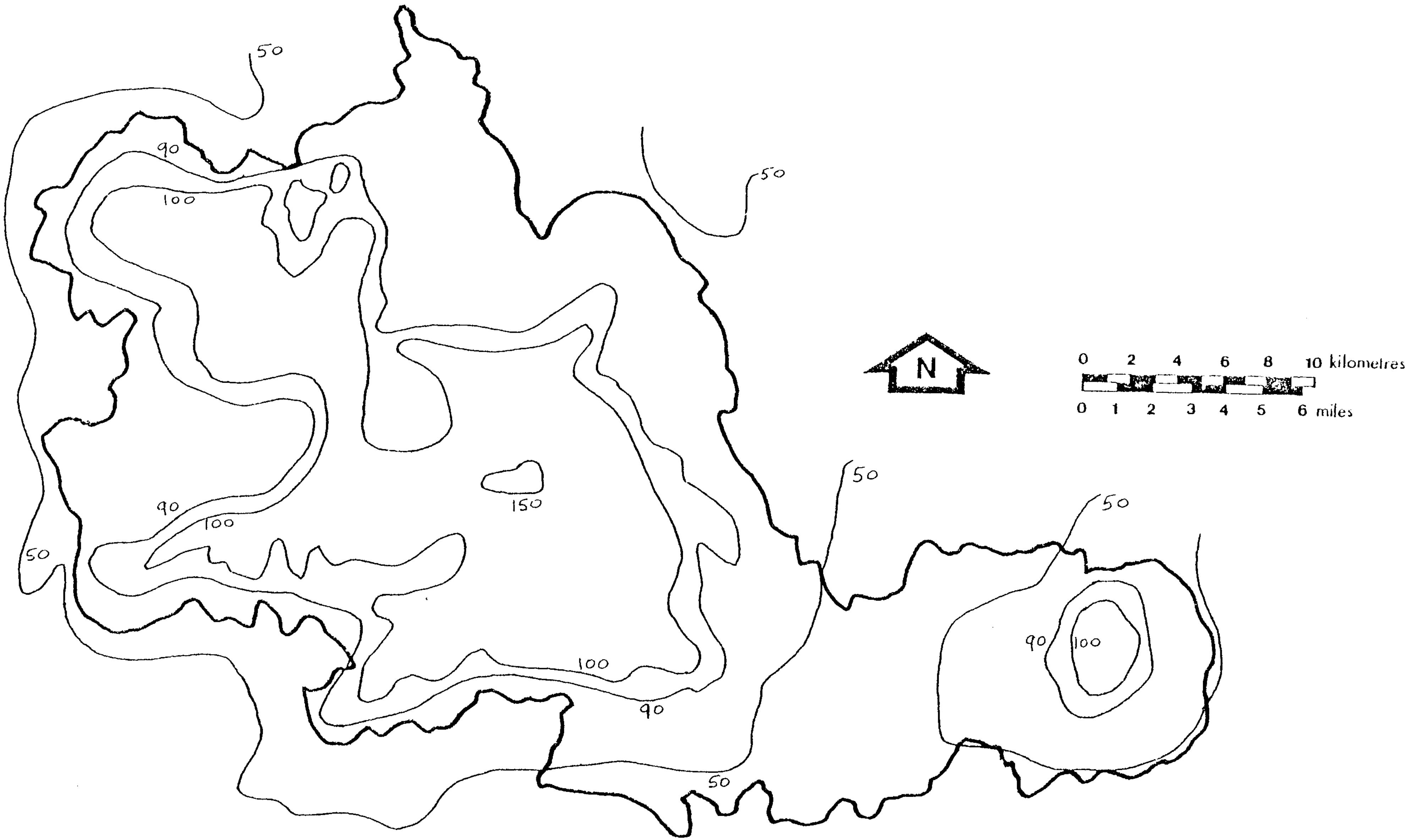


Fig. 6.13 Isopleth map of sulphur dioxide concentrations (1972/3) obtained by Warren Spring Laboratory.
(Source: DoE 1976)

Table 6.10 Percentage Explanation of Observed Spatial Variance Obtained from Disperson and Gifford Models in Three Sulphur Dioxide Studies

Case Study Area Author(s)	WMMC Pocock (1979)		New York Turner (1973)		Copenhagen Prahm and Christensen (1977)	
Model Types	Disperson	TAE (Gifford)	CDM	Gifford	CDM	Gifford
Percentage explanation of spatial variance (r^2)	62	57*	70*	70*	83	64

* Approximate figures

non-dispersion (Gifford) types of model. The other studies concern New York (TURNER 1973) and Copenhagen (PRAHM and CHRISTENSEN 1977) and the parameter values are obtained in each case from the square of the regression correlation coefficient r resulting from the regression of observed to predicted concentrations over a large urban area. In this research it was seen (Section 6.3.3, Table 6.7) that the urban diffusion model explained 62% of the observed variance with the diffusion parameters N = 5 and B = 0.30. Table C.8 of Appendix C.4 also showed that for N = 0 the percentage explanation fell by only around 5% - in other words, if concentrations are predicted individually for TAEs solely on the basis of the urban fabric activity types within them and with all dispersion from outside zones ignored, the model still explains 57% of the observed variance. Thus the error involved in reasserting the TAE principle that zones are 'functionally independent' is comparatively small for the given size of zone. In the other studies a zone size of $1km^2$ was used, together with measured meteorological parameters and a properly quantified emission inventory including both point and area sources in the CDM model. Considering especially the much more approximate emissions inventory and dispersion technique used in the research described in this thesis, it is possible to conclude on the basis of Table 6.13 that the performances of both the urban diffusion model and the TAE methodology compare well with the results of other equivalent studies.[1] Furthermore these prediction methods themselves compare very favourably with one example of the trend surface analysis technique which was undertaken by ANDERSON (1970) using measurement data alone for the National Survey sites within the West Midlands Conurbation; in this the 'best-fit' surface explained only 33% of the total observed variance in sulphur dioxide concentrations.

6.6.2 Summary, Comparisons and Conclusions in Relation to the Mapping Methodologies

The study of urban ambient noise was seen in Chapter 5.6.2 to have involved research in the areas of both measurement and prediction. The sulphur dioxide study has made no empirical investigation of air pollution measurement and the contribution of the research is made entirely within the sphere of prediction methodology. As in the noise study the three objectives of the TAE methodology have been investigated. In addition the urban diffusion model provides an alternative method, and in terms of the prime purpose of the research which was to test the TAE methodology, its role is the equivalent of the empirical survey and statistical analysis technique undertaken in the ambient noise study. The chapter now concludes with a summary and appraisal of the case study. For each of the three objectives of the TAE methodology the main conclusions are summarised, the key points of the empirical methods are given and comparisons are made with other equivalent studies. The same treatment is then given to the urban diffusion model.

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1. However, the fact that this test of model performance has been made on the same data set as that used for calibration means that the robustness of the model is untested, and the reliability of the quoted r value must be open to some doubt. As stated, the data are not available to allow this to be done.

(a) The test of the TAE hypothesis

(i) An 'analysis of variance' F-test was performed upon data consisting of the urban diffusion model predictions for examples of each TAE type. An F-ratio of 12.6 was achieved, indicating that a significant relationship exists at well above the 99% confidence level. Consequently the TAE hypothesis that TAE types are associated with statistically different sulphur dioxide concentrations was taken to be valid. The statistical validation of the area type classification by an analysis of variance F-test appears to be unique, for the only available equivalent classification, developed by the Warren Spring Laboratory, involves no clear zonal definition and has not been statistically tested (WILLIAMS 1978).

(ii) The ability to associate area types with typical pollution concentrations involves the implicit adoption of the Gifford model assumption of no significant between-zone diffusion; as well as the fact that the hypothesis was validated, the assumption is also supported by the evidence of the urban diffusion model, that only 5% of the total spatial variance between zones is due to diffusion.

(iii) As well as differences between the land use types of TAEs, differences also occur between the road network density types, thus substantiating the hypothesis asserted in Chapter 4 in the discussion of the design of the TAE typology, that the network density parameter acts as a surrogate for the 'land use intensity' factor which is a causal determinant of the areal emission strength.

(iv) While clearly constituting an acceptable method for classifying the sulphur dioxide conditions of the areas, the applicability of the TAE methodology to other pollutants is not tested and it is necessary to take a speculative approach based on hypotheses. The method works for sulphur dioxide because that particular pollutant is emitted on a wholesale basis from many sources and source types and at a low level, such that while variations within a zone are comparatively small (since emissions are so common and comparatively homogeneously distributed within such an area size) there are considerable between-zone differences (since emissions are often low-level and therefore disperse over between-zone distances); also, emissions may be classified by urban fabric area type. The same conditions may be expected to hold for smoke (total suspended particulates[1]), and possibly for lead and carbon monoxide. Other pollutants, such as those associated principally with particular types of industrial emissions, or with road traffic (e.g. hydrocarbons, nitrogen oxides) tend to be more localised and are therefore less strictly 'ambient', in the sense of the term as defined in Chapter 4.1. The TAE methodology is not assumed to be directly applicable to this type of air pollutant.

(b) Calibration of the TAE prediction model

(i) The TAE prediction model involves the allocation of a typical mean sulphur dioxide concentration to each TAE of any given type. The calibrated model itself is given in Table 6.1. This is a unique method for sulphur dioxide prediction, although it comparés with the traffic pollution prediction method described by MYRUP and ROGERS (1978). The method has been eschewed by other studies generally because of the suspicion that dispersion between zonal units would invalidate an attempt to predict the mean pollutant concentration purely on the basis of within-zone characteristics. This suspicion has not been substantiated by the evidence of this research.

(ii) Without the need to include dispersive factors, the computational

1. The conventional 'smoke shade' measurements as made in the National Survey are not suitable; BALL and HUME (1977) have shown that they are biased towards traffic pollution, while TURNER (1973) finds the CDM explaining only 40% of observed smoke shade variance.

procedure for determining zone concentrations is greatly simplified, and may be undertaken manually. This simple method should be compared with the need for computer calculations which applies even in the more elementary dispersion models of the modified Gifford type used in this research.

(iii) The error of estimate of the TAE prediction model has been difficult to assess due to the limited nature of the independent (observed) data, but it appears that the predicted area-mean concentrations of any given TAE zone as determined by the Table 6.1 are associated with an error of estimate which lies between 8.7 $\mu g\ m^{-3}$ and 17.7 $\mu g\ m^{-3}$. Although this means that the resulting confidence intervals are apparently rather large they should be compared with the working range of the model, which is at least 100 $\mu g\ m^{-3}$. From this perspective the errors are by no means untypical of air pollution studies, which commonly accept errors of estimate at around 50% (PRAHM and CHRISTENSEN 1977). The errors are also not large enough to prevent the model being used as was primarily intended in this research, as a means of identifying five groups of area types with distinctly different air pollution levels for mapping purposes.

(iv) Since the model relies for its predictions on a proportionality theory (Gifford model) with concentrations determined directly from calibrated emissions, the robustness of the model over time and as applied to other localities depends upon the constancy of the emissions 'calibration'. Clearly there is a seasonal emissions trend in the space heating element of the emissions, and general trends occur over periods of years in accordance with shifts in the pattern and general level of the consumption of sulphur-bearing fuels, and indeed in the sulphur content of the fuels themselves. Relative changes in the emissions of the different TAE types will result in changes of pattern, while general trends will result in changes in the general concentrations, as was observed in the comparison of the isoline maps for the Winters 1972/3 and 1975/6. The reliability of the model when applied to other localities depends upon the extent to which the calibration of the environment/urban fabric relationship holds over other areas. It should also be noted that the TAE prediction method takes no account of the effects of topography or the spatial variation of surface roughness due to the building fabric - in other words these factors have been taken as constant over the WMMC and their influence is 'built in' to the model calibration. As a result the extent to which the model can be generalised is not known. Further research is suggested in this field.

(v) A greater confidence in the robustness and generality of the model could be had if the emissions characteristics of area types were determined by quantitative emissions data, rather than calibrated empirically. The empirical calibration leans very heavily upon the data obtained at just 36 monitoring sites, and the reliability of the method is the more uncertain for the fact that it is assessed on the same data set. Nevertheless the principle of an emission inventory based upon the emissions typical of a range of urban fabric types is in itself a highly useful and original approach. It is more theoretically sound, reliable and precise than the alternative surrogate parameters such as housing density (MARSH and FOSTER 1967), building density (WILLIAMS 1978) and population density (BENARIE 1976), and yet an inventory of this kind is far easier to obtain over a large area like a county or a conurbation than the comprehensive zone-by-zone quantification of sulphur dioxide emissions, as used in the more complex models (BALL, 1978, PRAHM and CHRISTENSEN 1977). This is mainly due to the fact that the inventory is readily derived from the basic urban fabric data held by any local authority.

(c) Application of the TAE prediction model as a mapping method

(i) The mapping method is based on the grouping of TAEs into five categories of sulphur dioxide concentration, followed by the allocation of an appropriate group number to each TAE in the WMMC to give a choropleth map expressed in terms of the five groups. The grouping method, as discussed in the ambient noise study in section 5.5.1, results from a joint consideration of 'natural' breaks in the metric distribution and the urban fabric constitution of the groups. The mapping method itself is not unique in air pollution studies since it follows essentially the same procedure as the standard Gifford model, except that zone sizes smaller than those used in many Gifford applications (BENARIE 1976) have been shown to be feasible, and they are characterised by a typology of urban fabric data.

(ii) The choropleth mapping technique is more useful in planning contexts than is the more common isoline technique, since it allows the concentrations of area units to be compared, analysed and aggregated, and, in this particular application, related to urban fabric characteristics which are of interest to the planner especially at the strategic level. The general issue is dealt with in greater detail in Chapter 9.

(d) The urban diffusion model

(i) The urban diffusion model is well founded in established prediction theory, and the originality of the model is in its application, particularly through the use of an emission inventory expressed in terms of urban fabric activity types, rather than its method. It allows the area-mean sulphur dioxide concentrations of all TAE sized zones to be calculated individually, upon the basis of the particular composition of each zone and its neighbours expressed in terms of urban fabric activity types.

(ii) Since TAEs are disaggregated and their components reformulated to incorporate smoke control zone differences, the surrogate emissions data is no more precise than that used in the TAE methodology. Points (iii), (iv) and (v) discussed under the TAE prediction model also apply to the urban diffusion model.

(iii) The diffusion parameters are equivalent to those used in other contemporary studies (e.g. SHARMA 1976, GIFFORD and HANNA 1973). However since they are obtained through empirical calibration their general validity and accuracy is not known. A notable conclusion in respect of this uncertainty however, is that the inclusion of diffusion in the model adds only 5% to the percentage of total spatial variance in concentrations explained by the model. The model is therefore relatively insensitive to the diffusion parameters. As a result the additional computational complexity required for diffusion to be included may not be cost-effective in many instances particularly where it is pattern, rather than actual concentrations, that forms the focus of interest.

(iv) As with the TAE prediction model, it is not possible to achieve an independent estimate of the model's accuracy. Such estimates that are available relate to the accuracy in predicting point concentrations rather than TAE means; nevertheless 'best estimate' confidence intervals for the model have been given.

(v) The model does appear to exhibit an accuracy which is useful, and competitive with the accuracy of more complex models such as the CDM. Its main advantage over the TAE method lies in the ability to treat each TAE individually, and thereby to attain a more accurate spatial pattern. The inclusion of diffusion also gives rise to a more valid, 'continuous' pattern. The main disadvantage is that predicted concentrations are not directly related to types of area; in this respect the common classification of areas in the TAE method enables a more simple and useful expression of predicted conditions, and facilitates the comparison of sulphur dioxide conditions with other indicators.

As stated, the above conclusions are limited to the sulphur dioxide study itself, in isolation from the other attributes and broader perspectives laid out in the research problem. These broader issues are addressed in

Chapter 9, and in Appendix D a comprehensive summary of the empirical results of the case studies is given in which the sulphur dioxide conditions of the TAE types are presented in conjunction with other environmental and general descriptive data.

CHAPTER 7

CASE STUDY OF AREA APPEARANCE

7.0 INTRODUCTION

The object of this chapter is to describe the empirical case study through which the TAE methodology was tested in the case of area appearance. The reasons for including area appearance as a case study attribute have been given in Chapter 4.1. Apart from the general policy-related factors, these concern the need to test the TAE mapping methodology in respect of a wide, comprehensive range of the methodological problems posed by different types of indicator. The distinctive features of area appearance as compared with ambient noise and sulphur dioxide air pollution are, firstly, that the attribute is a 'composite' one (i.e. consists of a number of individual component aspects), secondly that it is a qualitative concept presenting considerable definitional and indicator (operational measurement) problems and results in data that are only of ordinal quality, and thirdly that the attribute is only measurable through area-based data. Since the methodological problems surrounding the empirical analysis and mapping of composite, ordinal, area-based indicators were not encountered in the ambient noise and sulphur dioxide studies, area appearance was included in the empirical research exercise as a means of testing the general applicability of the TAE methodology to indicators which present these kinds of problem.[1]

7.0.1 Empirical Research Method

(a) Aims

In accordance with the fundamental purposes of the research, the main aim of the case study was to test the TAE methodology using data obtained for an indicator of area appearance; in the absence of an appropriate,

1. Other examples of this type of indicator within the environmental field are recreational quality, industrial hazard, and various ecological concepts such as 'woodland quality'.

readily available indicator however, a secondary aim was an examination of the measurement issues and the development of an operational method of obtaining area appearance data upon which to make the tests.

(b) Objectives

The testing of the TAE methodology involved the now-familiar sequence of objectives;

(i) to validate the environment/TAE hypothesis in the case of an area appearance indicator,

(ii) to calibrate the TAE prediction modèl (in terms of median area appearance scores rather than mean conditions, owing to the ordinal properties of the measurements), and

(iii) to apply the TAE prediction model as a five-category mapping method for the WMMC. The development of an operational measurement method for a concept of area appearance, and the subsequent conduct of a field survey to obtain data upon which to pursue the above objectives, were also essential objectives.

(c) Hypotheses

The key TAE hypothesis remained identical to those tested in the previously-discussed case studies, holding the spatial variation in the area appearances of zones to be significantly associated with the spatial variation in their TAE type.

(d) Tests

In principle the test of the TAE hypothesis was also identical to that used in the other case studies, but the ordinal properties of the data dictated that instead of the 'analysis of variance' F-test, the equivalent non-parametric 'H-test' should be employed.

Area appearance was considered to be a time-independent concept and therefore the problem of testing for temporal statistical sampling error in the data was not encountered. It was however necessary to test the reliability and repeatability of the measurement method, particularly since the problems surrounding the development of an operational method for measuring area appearance were quite considerable. These problems will be seen to be due to the nature of the concept of area appearance itself. Unlike ambient noise and sulphur dioxide, area appearance is of interest as an environmental attribute only for its 'welfare' effects (see the discussion in Chapter 2.1). The degree to which such effects occur in association with a given type or condition of area appearance is poorly understood because of the subjective and unquantified nature of the perceptual, attitudinal and psychophysical issues involved. Consequently the research avoided any empirical consideration of these matters and instead a simple, readily-applied operational method was devised for classifying the appearance of an area on the basis of certain visual characteristics of its physical fabric.

Little equivalent contemporary research has been conducted, and so the comparison of the TAE methodology with other studies was necessarily somewhat limited.

7.0.2 Synopsis of the Chapter

The Chapter commences with a general review of the methodological problem of measuring a concept of area appearance; the major difficulty is seen to be the development of an indicator that reflects the human response to area appearance conditions. The approaches taken by other studies are examined, and the alternative, operational method devised for the purposes of this research is described. Section 7.2 presents the results of the test of the TAE hypothesis and the calibration of the TAE prediction model, and an extensive analysis of the reliability and repeatability of the measurement method follows in section 7.3, the results showing that the method was sufficiently robust to allow the TAE methodology to be tested on the data. Section 7.4 describes the application of the TAE prediction model as a mapping methodology, following the same 'five groups' technique as that used in the other case studies. The chapter concludes with a comparison of the method and the results against those of other equivalent research, followed by a concluding appraisal of the performance of the TAE methodology in the case study, seen as an example of its general application to ordinal, qualitative, composite, area-based environmental indicators.

7.1 THE BASIC PROBLEMS IN MEASURING AND REPRESENTING AREA APPEARANCE

In each of the case studies described in the previous two chapters, it was seen that there were considerable methodological problems in obtaining the data upon which to make an empirical test of the TAE mapping methodology. In the ambient noise study these problems were seen to centre on the errors of estimate associated with the high temporal and spatial variability of ambient noise; in the sulphur dioxide study the problem was to obtain sufficient measurement data to cover all TAE types when the necessary long-term monitored data were only available from a limited number of secondary source sites. In the area appearance study the main problem lay in the development of a method for achieving the measurements themselves. Since area appearance is an area-based concept that is in effect constant over time, the spatial and temporal sampling issues and spatial representation were not particularly problematical. Consequently the following discussion focusses chiefly upon the measurement issue.

7.1.1 A General Appraisal of the Problem

In the discussion of the significance of environmental issues in public policy (Chapter 2.1) a general framework for environmental measurement was established in terms of the relationship between the environmental stimulus and human response. It was asserted that environmental conditions pose a stimulus which elicits from man a response in the form of an effect upon his health, and/or social well-being ('welfare'). In the case of area appearance the effects of a 'stimulus' of a given condition of area appearance are essentially of the 'welfare' kind, centering on the individual's satisfaction with the perceived visual condition of an area. It was further stated in Chapter 2.1 that the ultimate purpose of environmental measurement in policy-related contexts is to achieve either a measure of the response directly, or a measure of the environmental stimulus in such a way that the measure is associated with the response. Clearly this basis for measurement requires some formal, systematic knowledge of the relationship between stimulus and response. The problem in the measurement of area appearance is that this relationship is theoretically complex and poorly understood. CANE (1977) and others (e.g. TROY 1972) have examined the problem in detail in the case of residential area quality, and have pointed to the conceptual, theoretical and practical difficulties which are encountered when investigating this kind of relationship, particularly in connection with the perceptual, attitudinal, and psychophysical issues involved, and the question of subjectivity. Some contemporary studies, discussed in the section below, have attempted to meet the problem through methods of measuring area appearance that seek to model the response through a simulation of the perceptual process. However, in view of the unquestionably weak theoretical basis for such a model, these methods must be considered to be of dubious validity.

This assessment of the essense of the measurement problem led to the adoption of a simple, alternative approach in this research, involving no more than an operational method for classifying the appearance of areas based on certain visual characteristics of their physical fabric. No empirical attempt was made to test or assert the extent or degree of any relationship between the resulting measures and the individual's satisfaction with the appearance of the area. This in fact is consistent with the approach taken in the other two attribute case studies in this research, except that in both cases there was substantial evidence in the literature for a relationship between the measures used (i.e. the A-weighted decibel indicators L_{10}, L_{90} and L_{eq}, and the mean sulphur dioxide concentration) and the response elicited in man's health and/or welfare. In the case of area appearance the operational method was based upon approaches adopted by the CIVIC TRUST (1971) and BUCHANAN (1973); in these instances there was no clearly established association between the resulting measures and the individual's response, owing to the difficulties already described. The studies have however both been used in operational policy contexts (the design of local plans in Merseyside and the development of the Tyne-Wear Urban Strategy respectively) and it was therefore assumed that such approaches could be of practical use in policy-directed studies, especially in view of the fact that the method involves the consideration of physical characteristics that certain planning policies may hope to influence or take into account. The method is summarised later in this section, and is examined in detail in connection with empirical results in section 7.3.

7.1.2 The Measurement Methods and Representational Approaches Taken in Other Studies

The usefulness of any method of measurement may be judged with respect to three key criteria:

(i) the relevance of the measurement method to the context;

(ii) the extent to which it is repeatable;

(iii) the degree to which it may discriminate between different conditions.

The general appraisal of the area appearance measurement problem given above, has dealt essentially with the difficulties in achieving a measure that is relevant to the public planning context. In this section and later in the chapter it is necessary to consider the other criteria also.

It has been stated that some contemporary studies have attempted to approach the problem of measuring area appearance by seeking to model the perceptual process of the individual respondent (e.g. FINES 1968, UNIVERSITY OF MANCHESTER 1976, SOUTH YORKSHIRE COUNTY COUNCIL 1978b). This type of study involves the application of a methodology that has been devised as a quite general approach to the measurement of concepts which are assumed to be 'composite', that is, concepts that are composed of several component attributes. There are four principal stages to this methodology:

(a) The identification of the range of component attributes which go to make up the composite concept which is of interest (the selection problem);

(b) The evaluation or 'measurement' of the condition of these component attributes on a scale which reflects the importance of changes in their condition (measurement and scaling problems);

(c) The weighting of the component attributes in a way which reflects the relative importance of their contribution to the overall concept (the weighting problem);

(d) The aggregation of component attribute measurements to produce an overall measurement of the concept of interest (the aggregation problem).

This four-stage methodology is of general interest in environmental studies since it provides a means of achieving aggregate environmental indicators - for example, 'primary parameters' describing the overall environmental conditions of a given medium or sector - and it will be discussed in more detail in the following Chapter 8. In the above mentioned type of area appearance study, the methodology has been used in effect as a model of the individual respondent's perceptual process.

The studies by the UNIVERSITY OF MANCHESTER (1976) and SOUTH YORKSHIRE COUNTY COUNCIL (1978b) describe two alternative types of approach using this methodology as a framework. They have termed these:

(i) 'subjective' or 'qualitative' evaluation;

(ii) 'objective' or 'quantitative' measurement.

These terms are misleading however, for reasons described below. The former approach involves the use of a sample respondent who is asked to make an assessment of his response to given examples of visual quality, either from field-visit observation or the examination of maps and photographs. A number of respondents may be used, in order to obtain a group sample. In relation to the theoretical basis of environmental measurement described in Chapter 2.1 and the above section 7.1.1, this is evidently a method aimed directly at measuring the perceptual response to a given visual environmental stimulus. In the second method a number of component attributes of area appearance are defined, under the assumption that these constitute the physical visual impressions that together determine the individual's perceptual response. Measures of these visual attributes (for example woodland, coastline, hedgerows etc., in the case of landscape attractiveness) are achieved, and are weighted and aggregated to achieve a single overall indicator measure that is assumed to correlate with human perceptual response (see the discussion in CLAMP 1976). Indeed methods such as multiple regression analysis have been used to achieve the weightings (coefficients) which maximise the correlation (SOUTH YORKSHIRE COUNTY COUNCIL 1978b).

In the former approach the four-stage 'composite indicator' methodology is understood to be the <u>implicit</u> basis of the individual's evaluation, while the latter approach involves a much more <u>explicit</u> application of the methodology as a framework for the measurement system. It is in fact this more explicit nature of the latter method that provides the only substantial difference between the two approaches, for in the final analysis both are equally subjective and qualitative. This is seen by noting that the latter approach merely makes the subjective judgements (such as component identification, measurement and weighting) more explicit - not more 'objective' - and that although the component measurements may be made in interval or ratio data the fact remains that the individual's response, which the method attempts to simulate, may itself only be assessed on qualitative (i.e. ordinal or nominal) scales (CANE 1977, HODGINS 1976). It may be argued that the latter of the two methods is the more 'objective' in the sense that its results are more repeatable - in other words, if the aggregation procedure is calibrated against the group median response of a sample of respondents, the resulting method is a repeatable prediction technique for estimating the 'median' individual's response. The weakness in this argument is intrinsic to this use of the methodology itself, for there is as yet no clear evidence that the human response mechanism works in any way like that suggested by this model.

Consequently it was decided that neither the direct measurement of response nor the attempt to simulate the stimulus/response relationship should be used in the research. Instead a simple, readily-applied operational method for classifying areas based on certain of their visual characteristics was devised. Examples of this kind of approach (CIVIC TRUST 1971, BUCHANAN 1973) have already been mentioned. Referring to the discussion of definitional issues in Chapter 2.1 it is seen that these methods are clear instances of the 'operational' type of definition, while the methods based upon notions of response are more closely connected with the 'conceptual' type of definition; it is argued that the 'operational' definition is more appropriate where the science itself is new and speculative and is not based upon established precepts. The operational methods rely upon objective criteria for the definition of the measurement scales and are therefore easily repeatable. The method used by the Civic Trust incorporates direct measurement of the visual condition of the physical fabric as a means of assessing residential area quality, involving measurement scales expressed in ordinal categories such as 'x% of paving stones broken' or 'y% of the street affected by litter'. The Buchanan system (described in detail in section 7.3) involves a prediction-based method which associates environmental 'deficiency scores' with a set of categories (consisting of 'clusters' of factor scores) of residential area type. The operational method used in this research was based on a combination of these two systems, and is summarised in the section below.

The mapping of area appearance is a relatively simple task once an appropriate measurement method has been decided. The alternatives, which apply both to the operational methods and the measurements supposedly related to response, are spatially comprehensive area-based measurement, or area-based prediction. Examples of the measurement-based method are to be found in FINES (1968) in which measurements of response are obtained for 1sq km grids, and the Civic Trust method in which individual street blocks are measured. Examples of the area-based prediction method have already been mentioned; the 'response' predictions obtained by South Yorkshire County Council involved the use of 'predictor' components assessed over 1 sq km grids, while the Buchanan system entailed the prediction of 'deficiency scores' for census Enumeration Districts (approx. 0.5 km X 0.5 km) on the basis of their residential area type. From this it is seen that the methodology of the Buchanan system is very similar to the TAE methodology except that a standard, regular zoning system is not used. It was therefore decided that the Buchanan system (which is also similar to an approach used by KAIN and QUIGLEY (1970) in the USA) should form the basis of the approach taken in this research, but with modifications to the measurement method allowing elements of the Civic Trust technique to be incorporated in order to broaden its comprehensiveness.

7.1.3 Summary of the Measurement Method Used in this Research

The measurement method used in this research is summarised below, and a detailed discussion of its key features is undertaken in section 7.3, in which statistical tests of its repeatability and robustness are described and assessed.

As stated, the operational method is essentially a means of classifying areas based on certain visual characteristics of their physical fabric. It is not possible totally to divorce any assessment of visual factors from the issue of individual response however, since a 'visual characteristic' is an entity that is operationally defined by the fact of being observable to the human eye. Consequently it is inevitably necessary at some stage in the 'measurement' (here, the classification) of visual characteristics to use the individual as part of the 'measurement tool' - that is, as part of the means of probing and recording the condition of the visual environment. In the method of this research a field surveyor was used in this way as part of the operational means of conducting the classification. The method differed from the simple measurement of human response by the fact that the surveyor recorded - or 'scaled' - the results of his visual observation with respect to a pre-defined set of 'description statements', describing different conditions of each of a set of pre-defined aspects or 'component attributes' of the visual environment. The measurement procedure is summarised as follows:

(i) Four component attributes of area appearance were defined: (a) building decay, (b) dereliction, (c) visual intrusions, and (d) aesthetic quality.

(ii) A set of ten 'description statements' was devised for each attribute, these being shown in Tables 7.1 - 7.4; each statement described in predominantly qualitative terms the condition of an area with respect to the attribute in question, the statements being ranked from least prominence to most prominence of the attribute in question, thus allocating a rank score between 0 and 9 to each statement.

(iii) For a given unit of area (discussed later) the surveyor made an appraisal of the visual appearance of the area with respect to each of the four attributes in turn, scoring his appraisal in terms of the description statement with which it was most closely matched.

(iv) The surveyor then made an appraisal of the overall appearance of the area by similarly matching his appraisal against an ordered set of ten possible area appearance description statements given in Table 7.5, under the condition that (so far as might be consciously possible) his assessment was based on an overall consideration of the factors that had been involved in his assessment of the four component attributes. In this way an intuitive aggregation of the components into an area appearance rank score between the values 0 and 9 was achieved, the only purpose of the individual attribute appraisals being therefore effectively to focus the surveyor's attention upon those elements of the visual environment which had been selected as the components of the operational method.

Section 7.3.2 shows, through a statistical analysis of the data collected by this method, that the measures of the four attributes are correlated both amongst themselves and with the overall area appearance measure. The identification and definition of the four component attributes used in the method was achieved as a result of an appraisal of contemporary studies. As already stated, research (see CANE 1977) has shown that a wide variety of visual attributes are correlated with individual perception and response, in a complex way which is poorly understood. Since the purpose of the research described here is not to mirror the perceptual response but simply to define an operational method for classifying the visual appearance of an area, there are clearly many visual aspects that could be chosen to provide a basis for this. The selection of the four attributes described above was to some degree quite arbitrary, but certain specific criteria were laid down.

Table 7.1 Description Statements for Scoring Building Decay

Score	Description Statement
9	All buildings clean, well maintained, painted, sound roofs.
8	Very occasional buildings needing attention to paint, windows, etc.
7	Some attention to cleaning and painting necessary occasionally.
6	Sound structure, no repairs required but frequent attention to paint and cleaning needed.
5	Generally rather shoddy appearance, general need for painting, roof repairs, repointing.
4	Paint peeling, repairs often needed.
3	Frequent dirty and unkempt buildings, much repair needed.
2	Structural attention required, predominantly dirty and unkempt.
1	Frequent semi-derelict buildings, broken windows, tiles and bricks missing.
0	All buildings in semi-derelict condition.

Table 7.2 Description Statements for Scoring Dereliction

Score	Description Statement
9	No unoccupied or damaged buildings, no wasteland.
8	Very occasional unoccupied or damaged buildings (1 or 2).
7	A few unoccupied or damaged buildings, or a little wasteland.
6	Noticable unoccupied or damaged buildings, or noticeable wasteland.
5	Unoccupied and damaged buildings, or wasteland and dumping.
4	Some demolition sites, probably together with wasteland and dumping.
3	Noticable demolished, wasteland sites and derelict property over 10-20. of area.
2	Frequent demolished, wasteland sites and derelict property over 20-50% of area.
1	Generally demolished or wasteland sites, 50% of area.
0	Totally derelict.

Table 7.3 Description Statements for Scoring Visual Intrusion

Score	Description Statement
9	No unsightly intrusions.
8	Very occasional slight intrusions (e.g. a few distant pylons, chimneys, occasional litter).
7	Occasional slight intrusions (e.g. distant pylons and factories, a little street litter).
6	Some slight to moderate intrusions (e.g. nearby flyover, factories, chimneys, some street and garden litter).
5	Noticeable moderate intrusions (e.g. nearby gasholders, railway arches, flyovers).
4	Frequent intrusions, moderate and occasionally severe.
3	Appreciable moderate and noticeable severe intrusions.
2	Generally intrusive and ugly, noticeable major intrusions.
1	Predominance of ugly and major intrusions.
0	Complete dominance of major, ugly intrusions.

Characteristics contributing to visual intrusion: litter, pylons, dumping and tip sites, unkempt railway embankments and arches, gasholders, cooling towers, industrial sites.

Table 7.4 Description Statements for Scoring Aesthetic Quality

Score	Description Statement
9	Complete dominance of very attractive surroundings.
8	Predominantly attractive, often very good, some occasional omissions.
7	Attractive on the whole, some very good, some omissions.
6	Rather attractive in general, a few very good sites but noticeable sterile areas.
5	Pleasant impressions in general but nothing outstanding.
4	Noticeable quite pleasant impressions but considerable sterile areas.
3	Generally rather sterile but some occasional quite pleasant sites.
2	Generally sterile, just occasional rather pleasant sites.
1	Predominantly sterile, just a few very infrequent exceptions. (e.g. occasional hedge or pleasant building).
0	Nothing at all attractive, totally sterile.

Contributions to attractive and pleasant impressions: pretty, well-kept gardens, walls, fences and hedges; mature trees and grassland, colourful avenues, interesting or historical sites and buildings; architecturally stimulating or pleasing buildings.

Table 7.5 Description Statements for Scoring Overall Area Appearance

Score	Descriptive Statement
9	Very attractive, nothing unpleasant at all.
8	Attractive but very occasional exceptions.
7	On the whole good and pleasant but some exceptions.
6	Pleasant in general but noticeable amount of rather mediocre conditions.
5	Rather mediocre in general but few unpleasant impacts.
4	Predominantly mediocre, with some unpleasant impacts.
3	Generally rather shoddy, some severe impacts.
2	Shoddy in general, with severe impacts.
1	Shoddy, many grim areas.
0	Intolerably unpleasant area.

One criterion to be fulfilled by component attributes was that they should be subject to ubiquitous measurability - in other words, that the attributes should be defined such that scores might be obtained for all types of area, be they rural, urban, built-up, residential, industrial, or whatever. Moreover in order that the measures might discriminate between one area and another (a necessary criterion for useful measurement, as established at the introduction of section 7.1.1), the definitions should be such that a general variability in the defined characteristics obtains over the study area.[1] It was also necessary that attributes should be 'individual' in the sense that visual aspects included in one should not feature in any of the others. A final requirement was that the visual aspects of interest in planning contexts should be covered as comprehensively as possible; these will inevitably be associated with the aspects provoking human response and since an investigation of this was beyond the scope of the research it was decided simply to ensure that the definitions of the attributes covered those aspects featuring most commonly in other assessment systems (e.g. CIVIC TRUST 1971, BUCHANAN 1973, KAIN and QUIGLEY 1970). Consequently the four attributes simply represent some of those attributes that have featured in contemporary research, and the content of the description statements was similarly derived from the categories used in other studies - for example the 'building decay' statements are effectively equivalent to a combination of a number of 'building condition point score' categories used by the CIVIC TRUST (1971).

This section has involved a detailed examination of the measurement problem, and a further appraisal of the method used in this research is made in section 7.3. It has been necessary to make a study in this depth

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1. For example, an attribute 'woodland cover' would score 'zero' over the greater part of the conurbation, and would not therefore be a useful differentiator of the conurbation's area appearance.

prior to the description of the testing of the TAE hypothesis and calibration of the TAE prediction model, because the case study itself has no meaning until it is made clear exactly what the attribute under investigation consists of. Having now achieved this the main objectives of the case study may be discussed.

7.2 THE TEST OF THE CENTRAL HYPOTHESIS AND THE CALIBRATION OF THE TAE PREDICTION MODEL

In principle the hypothesis and prediction model are the same as those tested in the ambient noise and sulphur dioxide studies; the hypothesis asserts that spatial variation in area appearance is significantly associated with the variation in the TAE type of zones, and the prediction model involves the allocation of a 'typical' area appearance to each TAE type. The central difference between the area appearance study and the previous studies in the research lies in the scale properties of the measurements, for while the cardinal properties of the data used in the previous studies allowed a parametric statistical analysis (the F-test), the ordinal properties of the area appearance measurements meant that a non-parametric statistical analysis was necessary. As stated in the introduction to this chapter, this therefore provides a case study of the general application of the TAE methodology to ordinally-measured environmental indicators.

7.2.1 Derivation of the Data for the Test and Calibration Exercises

The data for testing the TAE methodology were obtained from a field survey which ran contemporaneously with that for the ambient noise study. Thus the survey routine was as already described in Chapter 5.2.1 and Appendix A, with three survey phases; the first involved nineteen sample TAEs, one of each type; the second a set of eleven TAEs to test for the variation in observed conditions between TAEs of the same type; and the third a return visit to seven TAEs to test for the variation in conditions over a 2-6 month interval. Since area appearance is a constant concept over this time period the phase 3 survey allowed, in this study, a method of testing the constancy of the surveyor's interpretation of the measurement method, as described in section 7.3.

Area appearance was measured within each of the five 'locations' in each TAE as defined in Fig. 5.3(b) of Chapter 5. Thus the results of the Phase 1 survey consisted of five sampled ordinal score measures of area appearance within a sample TAE of each type, as shown in Fig. 7.1; it was this data set that was used to test the TAE hypothesis and calibrate the prediction model.

7.2.2 The Test of the TAE Hypothesis

As with the other studies, the statistical test of the hypothesis investigated whether the measurements of area appearance made in TAEs of different kinds came from different statistical populations, and, again following the principles already set out in the previous case study chapters, the analysis was made upon the null hypothesis that the distribution of observations given in Fig. 7.1 was the result of the random statistical sampling of one single parent population covering the whole study area. The two previously-discussed tests of this hypothesis involved the comparison of between-sample and within-sample variances; in the case of ordinal measurements however, statistical parameters such as the variances and means of samples are not valid and so it is necessary to use a non-parametric statistical test of the null hypothesis. Three such tests are possible: the Chi-square test, the 'Extension of the Medians' test, and the 'Kruskal-Wallis One-way Analysis of Variance by Ranks' test, the latter being the most powerful since it preserves the magnitude of the measurement scores most fully (SIEGEL 1956). Consequently the Kruskal-Wallis 'H-test' was taken as the non-parametric equivalent of the 'Analysis of Variance F-test' for testing the hypothesis.

Fig. 7.1 Distribution of observed area appearance scores in sampled TAE types.

Area appearance (scores)	6B	4A	6A	8B	8C	1B	4B	1A	0A	2A	5B	5A	0B	7C	5C	7B	7A	0C	3C
9		1	1	1															
8	1					1	1												
7	2	2	2		1				1										
6	2	1	1	2	2	2		2		2									
5		1	1	2	2	1	3	1	1		1								
4						1	1	1	3		3	1		1					
3								1		2		1			1				
2											1	1	4	1	1	3	1	1	
1										1		2	1	3	2	2	4	2	2
0															1			2	3
TAE type	6B	4A	6A	8B	8C	1B	4B	1A	0A	2A	5B	5A	0B	7C	5C	7B	7A	0C	3C

The Kruskal-Wallis test involves an initial ranking of all observations in the data set: thus the 95 measurements shown in Fig. 7.1 were each given a ranking, with tied scores being allocated the median ranking of the tied range. Each sample TAE therefore contained five rank 'measurements', and these were summed to give a 'sum of ranks' parameter R_j for each of the j sample TAEs (j = 1,19), as shown in Table 7.6. The Kruskal-Wallis test investigates whether the distribution of R_j values between the samples is likely to have occurred by the chance sampling variations deriving from a single parent population, or whether it indicates that statistically significant differences exist between the samples. This is achieved by assessing the significance of the parameter H, where H is given by

$$H = \frac{\frac{12}{N(N+1)} \sum_{j=1}^{K} \left(\frac{R_j}{n_j} \right) - 3(N+1)}{1 - \frac{\sum T}{N^3 - N}} \qquad 7.1$$

(SIEGEL 1956)

where K = 19 samples, n_j = 5 measurements per sample, giving N = 95 total number of measurements, while T is a 'tie correction' parameter relating to the number of tied scores. The Phase 1 survey data gave a value of H = 36.3, the significance of which was assessed by Chi-square tables since H is distributed approximately as Chi-squared with K - 1 degrees of freedom (SIEGEL 1956). From the tables, with 18 degrees of freedom H is significant at the 1% level for H ≐ 34.8, and at the 0.1 % level for H = 42.3. Thus there was found to be a less than 1% chance that the distribution of observed area appearance scores could have occurred by the random sampling of a single parent population; consequently the null hypothesis was rejected and it was concluded that significant variation in area appearance measurements occurs between TAE types.

It should be noted however that the survey method made possible the inclusion of bias which, unlike that encountered in the ambient noise study, could not be evaluated and corrected. The fact that each sample was observed on a different day was not seen to be a possible source of

Table 7.6 Area Appearance Median Scores, Kendall 'Sum of Ranking' R_j, and ranking of R_j

TAE Type	6B	4A	6A	8B	8C	1B	4B	1A	0A	2A	5B	5A	0B	7C	5C	7B	7A	0C	3C
Area Appearance Median Score	2	2	2	3	3	3	4	4	5	6	5	7	7	8	8	7	8	8	9
Kendall 'Sum of Ranks' R_j	69	79.5	79.5	115	123.5	130	157	180	186.5	233	240	326	336	351	351	352	371.5	409	437.5
Ranking of R_j	1	2=	2=	4	5	6	7	8	9	10	11	12	13	14=	14=	16	17	18	19

bias since it was taken that, unlike ambient noise, area appearance was constant over time. However the fact that the samples of each TAE type were all made from within a single TAE zone could have been a source of bias if significant between-zone variations had occurred independently of the TAE typology, as was found to be the case in the ambient noise study. Because of the non-parametric properties of the data it was not possible to correct for this as was done in the ambient noise study, and the research was limited to the observation that given differences between the median scores of zones of the same type (obtained from comparison of Phases 1 and 2 results, see section 7.3) occurred very much less frequently than between the median scores of TAEs of different types (see section 7.2.3 following). From this it was assumed that the variation between TAEs of the same type did not contribute sufficient variation to explain the observed variations shown in Fig. 7.1, upon which the null hypothesis was rejected.

7.2.3 Calibration of the TAE Prediction Model

As in the previously-discussed case studies, the objective of the model calibration exercise was to associate each TAE type with a representative indicator value. The non-parametric nature of the data invalidates the use of a mean indicator value and it was decided instead to represent each TAE type by a median indicator score. These were obtained from the medians observed in the Phase 1 survey, the data from which were shown in Fig. 7.6. The medians are presented in TAE matrix form in Table 7.7; this matrix therefore constitutes the calibrated TAE prediction model.[1] The table shows the median area appearance score predicted for any TAE of a given type. In the Table 7.6 already presented these median scores are given

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1. A discussion of the significance of the results is made in section 7.4.

Table 7.7 Matrix of the TAE Prediction Model for Area Appearance Scores

LAND USE	ROAD NETWORK DENSITY		
	A. Dense	B. Medium	C. Sparse
0. Residential	5	7	8
1. Industrial	4	3	*
2. Commercial	6	*	*
3. Open Space	*	*	9
4. Res/Ind	2	4	*
5. Res/Comm	7	5	8
6. Ind/Comm	2	2	*
7. Res/O.S.	8	7	8
8. Ind/O.S.	*	3	3

*: Insignificant proportion (less than 0.5%) of WMMC area in the category.

together with the corresponding Kendall 'sum of ranks' parameter R_j. From this it is evident that the R_j parameter is more sensitive in its ability to discriminate between the conditions of different TAE types than the 'median score' parameter. It was not considered appropriate to use the R_j parameter as the basis of the TAE prediction model however since it is numerically abstract, while the 'median score' can be related to its relevant 'description statement', and is therefore of more use in relating an area type to a comprehensive description of its 'typical' environmental condition. In Section 7.4.1 however it is seen that the R_j parameter, rather than the median score, is used to discriminate between TAE types as part of the grouping process.

The most striking fact about the TAE prediction model, particularly when compared with those for ambient noise and sulphur dioxide, is the large difference that exists between the predicted conditions of different land use types, and the relatively smaller difference between the conditions of different network density types. In both of the TAE prediction models of the other studies the explanatory powers of (i.e. the variances associated with) the two urban fabric parameters were very similar. The above characteristic of the area appearance model indicates that the spatial variance of area appearance is largely associated with land use, the only notable variation with network density being in the 'residential' land use category where, as suggested by the hypothesis given in Chapter 4.3, the higher densities are associated with poorer area appearance. The dominant influence of land use type is not altogether unexpected considering that the criteria expressed in the 'description statements' used in the operational method for measuring area appearance are strongly related to built form characteristics; for example the measurement system has a negative bias towards factors associated with industrial land use, and this is reflected in the results of the calibration exercise.

The ordinal nature of the data makes the accuracy of the model difficult to assess. This is because it is possible neither to obtain an error variance nor to talk in aggregate terms about median score deviations. All that may be given by way of appraisal is a summary of the comparison of the model predictions with the results of the Phase 2 survey, which acts effectively as a test of the model's predictions (see section 7.3). The Phase 2 survey results showed that in 73% of the TAEs surveyed[1] the observed median score was within one score value of the predicted score,

1. The fact that only eleven TAEs were surveyed in Phase 2 further limits the reliability of this accuracy assessment.

and in no TAE was the observed median more than two score values different from the predicted score.

In common with the other studies the TAE prediction model was used to obtain an aggregate assessment of the area appearance conditions found in the WMMC expressed in terms of a cumulative frequency distribution. The previous case studies have discussed the need to 'group' the TAE prediction model before it can be applied as a mapping method, and in section 7.4 a grouping method is described through which the mapping of area appearance was achieved. The cumulative frequency distribution is shown in Fig. 7.2, and was obtained in the same way as in the other

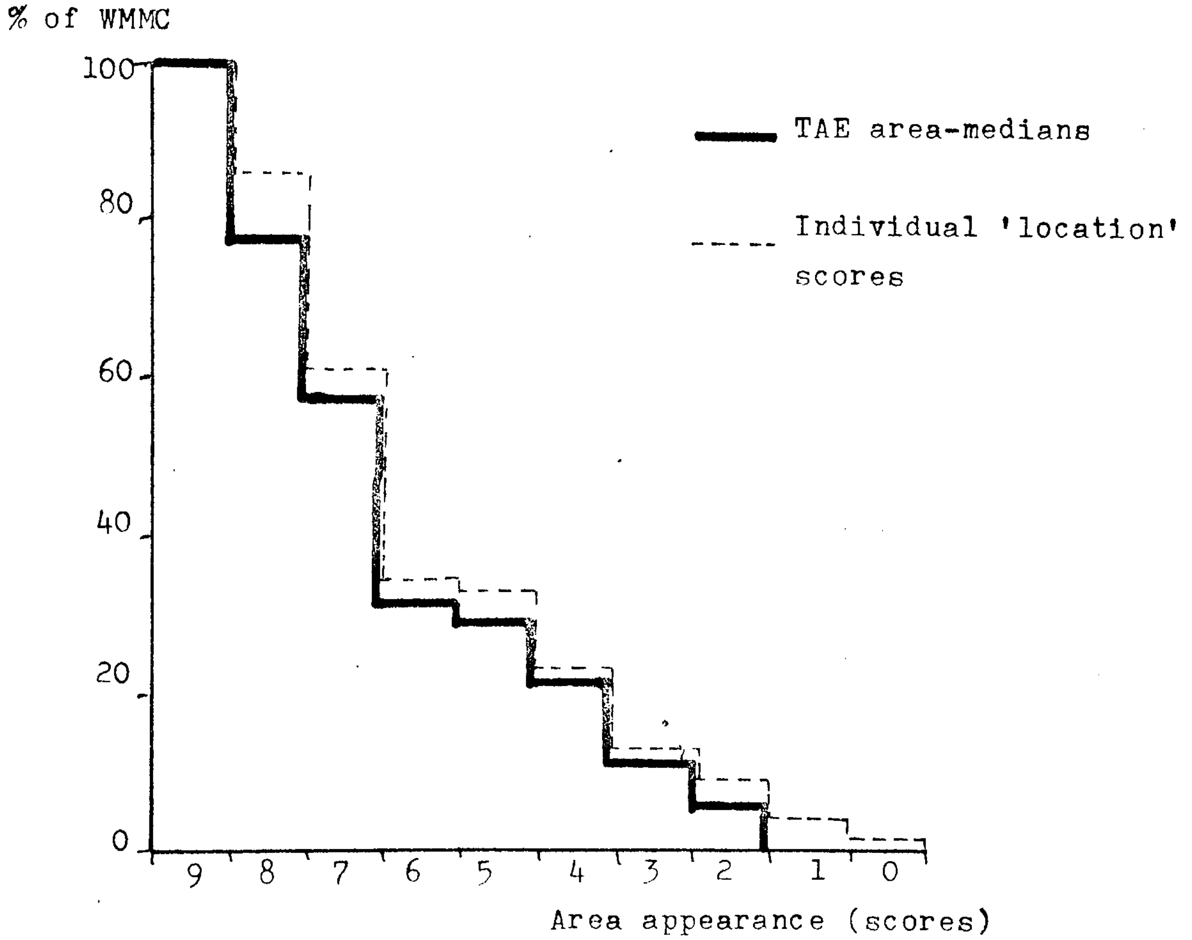

Fig. 7.2 Cumulative frequency distribution of area appearance conditions in the WMMC.

studies, but must be represented through a histogram rather than through a continuous curve since the ordinal units are discrete; it should also be noted that while for convenience the graphical display gives equal unit sizes to the histogram blocks this should not be interpreted as an equal-interval representation of area appearance measurements. The data in this case study is particularly useful for comparing the distribution of the median conditions of TAE units with the distribution of conditions through the study area independently of the zoning system. This is because unlike the sulphur dioxide study there are measures of conditions at the sub-zone level, while the data set is simpler and smaller than in the noise study and, with the histogram presentation, this makes the contrast easier to interpret. The second histogram in Fig. 7.2 is therefore that obtained by taking all 95 observed values in the Phase 1 survey, each weighted by the amount of the WMMC land area in the TAE type from which the measurement was sampled. It is seen from the figure that the distribution of TAE medians is less susceptible to extreme values than the spatially disaggregated measurements. This is to be expected from the nature of the spatial variation of conditions - in other words, while isolated locations of score 0 are found, it is less likely that the median value of a whole TAE zone will be of score 0. This finding is an interesting illustration of the issue of zone size, discussed conceptually in Chapter 3.4 where it was stated that between-zone variance in conditions would decrease as zone size was increased; it is essentially this point which is validated by the data in Fig. 7.2.

This section has presented non-parametric methods whereby the TAE hypothesis was validated and the prediction model calibrated for area appearance measures. It is assumed that the same procedure could be adopted for any ordinal, area-based indicator.

7.3 ANALYSIS OF THE OPERATIONAL METHOD FOR MEASURING AREA APPEARANCE

The purpose of this section is to describe in detail the measurement method for area appearance, and to discuss the results of a number of statistical tests that assessed the nature and reliability of the method, and the repeatability over a period of time; the variation in appearance between TAEs of the same type is also discussed. These tests were the best available for assessing the measurement and sampling errors of the case study.

7.3.1 Detailed Description of the Measurement Method

A description of the measurement process has already been given in section 7.1.3. Here a number of the key issues at the heart of the operational method are discussed in more detail prior to the empirical examination of the measurement method in the second part of this section. The issue of the subjectivity of area appearance measurement methods has already been mentioned (section 7.1.2) as a factor constraining the repeatability of such measurement methods. The operational method of measurement has been seen to minimise the effects of subjectivity - and therefore to maximise the repeatability of the method - through the use of objective measurement criteria expressed in the form of 'description statements'. These derive from the methods used by CIVIC TRUST (1971), BUCHANAN (1973) and others, and contrast with the methods which simply seek to measure subjective perceptual response through, for example, asking the surveyor to 'rank the sample area with respect to building decay on a scale from 0 to 9'. It has also been stated however that an individual respondent is necessarily used in the operational method as part of the 'measurement tool' and therefore subjectivity is not eliminated from the method. This is clearly demonstrated in the qualitative terms used in the description statements such as 'generally', 'appreciable', 'noticeable', 'occasional', etc. (see Tables 7.1 - 7.5). The effects of this subjectivity on the repeatability of the method could not be fully tested in this research because only one respondent was used, but such factors as could be addressed are discussed in section 7.3.2.

The description statements necessarily play dual attention to both the quality and the quantity of the component attributes within the sample area; this being so it was considered that the methodological measurement problem would be simplified if each attribute was designed to include either purely 'positive' or purely 'negative' factors in respect of area appearance.[1] The methodological advantage of this is that the quality and the quantity of the attribute concerned act unidimensionally in the evaluation of attribute condition, either enhancing or detracting from the concept of overall area appearance. To illustrate this point consider the way in which the visual properties of buildings contribute to area appearance; as noted by SOUTH YORKSHIRE COUNTY COUNCIL (1978b), the visual properties of buildings include those aspects which may enhance, as well as those that may detract from, overall area appearance. Any attempt to measure an attribute describing 'visual building condition' would require the 'positive' factors of attractive buildings to be balanced against the 'negative' factors of poor quality buildings before a measurement score could be made. Furthermore it would be necessary to allocate an intermediate score for areas where there are no buildings at all, and consequently such an intermediate score would be envisaged as describing an area appearance condition which would also be equivalent to some combinations of good quality and poor quality building features - clearly a difficult situation to conceptualise, and one where the validity and usefulness of the resulting measurements are dubious. In the method of this research, 'negative' and 'positive' aspects of 'visual building condition' are considered separately; the 'building decay' attribute treats important negative factors[2] against a standard 'null' conditions (score = 9) in which no decay is evident (therefore where all buildings are well-

1. Consequently, 'dereliction', 'building decay' and 'visual intrusions' were designed to be 'negative' components, and 'aesthetic quality' a 'positive' component, of overall area appearance.

2. Note that not all negative factors associated with buildings are included in this; for instance the architectural ugliness of buildings is omitted.

maintained and in pristine condition), while the positive visual aspects of buildings are included in the 'aesthetic quality' attribute against a standard 'null' condition (score = 0) in which the area is barren of aesthetically pleasing impressions.[1] Thus in each case there is neither a need to balance positive against negative factors, nor a problem about scoring areas where there are no buildings, since in their absence factors associated with buildings simply do not contribute to a deviation from the standard 'null' condition. The separation of positive and negative factors, while conceptually difficult to maintain when the perceptual process is considered, is perfectly feasible and valid in the kind of operational classification method used in this research, and indeed it not only enhances the operational simplicity of the measurement procedure but increases the heuristic value of the 'component measurement' stage in forcing the surveyor explicitly to consider and evaluate the individual component aspects of the operationally-defined concept of area appearance.

One final methodological problem in the measurement procedure, and one not fully solved, is that of double-counting, in other words the inclusion of a given visual aspect in more than one attribute measure. For example a fly-tip site is an element in both the 'visual intrusion' and 'dereliction' attributes. Outside of the field of psychological studies there is no satisfactory solution to the problem except to design the scoring system to minimise the possibility of visual aspects becoming double-counted. To an extent too the impact of the problem in the overall evaluation of area appearance is mitigated by the aggregation method used, and the lack of independence between attributes which results from possible double-counting is also of less significance to the overall evaluation

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1. Note that standard 'null' conditions of 'negative' attributes are scored 9 while those of 'positive' attributes are scored 0; this is in order to maintain consistency with respect to their contributions to overall area appearance.

because in any case an intrinsic association was detected between the four component attributes (see section 7.3.2 following).

It has been stated that area appearance is an area-based concept, and it is therefore imperative that the operational measurement method should include a specification of the size of area to be considered in any given measurement. Sample measurements were carried out at each 'location' in the sample TAE and so it was essentially this size of area (0.25 sq km, as shown in Fig. 5.3b) that was measured. It will be remembered that noise conditions were measured at four sites within each 'location'; in passing from one site to the next the surveyor transected the unit a number of times and it was partly through his observations during this somewhat arbitrary 'walkabout', and partly from longer deliberations entertained at each site, that the surveyor obtained visual information upon which to evaluate the visual conditions of the 'location' unit. Building decay and dereliction were easily assessed on this basis since they simply relate to the physical fabric within the observed unit of area; visual intrusion and aesthetic quality on the other hand present difficulties concerned with the issue of views. This is because their determination includes an appreciation of the visual condition of the whole panorama up to whatever natural horizon may exist in the area concerned. Consequently there are instances where the 'views' element in these attributes is evaluated on information appertaining to land outside the 'location' unit, indeed in some cases to areas at some considerable distance from the sample TAE itself. The methodological problems in treating the views issue are further complicated by the differences in panorama at different types of site; in rural and suburban areas and at topographically exposed locations the scope of the panorama may extend to a horizon many kilometres distant, whereas in areas of high rise, high density built environment the panorama is frequently curtailed at distances beyond 100 m. This problem of consistency is discussed in the context of landscape attractiveness studies by

SOUTH YORKSHIRE COUNTY COUNCIL (1978b); no particular solution being offered by this source however, it was decided to follow the method of directly measuring the attributes taking into account whatever views happened to be present at the given location, up to the natural horizon, thus accepting the resulting inconsistency in the area surveyed. The fact that conditions outside the sample TAE were consequently included in the observations was not seen to be inconsistent with the other case studies in the research, for both ambient noise and sulphur dioxide conditions were measured as they existed at given points despite the fact that contributions to those given conditions knowingly emanated from beyond the TAE boundary. In those cases the attempt to predict such conditions upon the basis of within-zone characteristics was found to be successful due to the fact, discussed in section 6.6, that the between-zone 'dispersion' element was comparatively small, and that spatial autocorrelation between zones made 'diffusion' a less significant cause of spatial between-zone variation. In this study too the fact that the TAE hypothesis was validated shows that the influence of views on the resulting overall measurements was not significant enough to undermine the prime purpose of the exercise, this being to allow zone conditions to be predicted solely upon <u>within-zone</u> characteristics.

Having obtained measurements of the four component attributes for a given location unit, an overall area appearance score was obtained through an aggregation procedure of the 'subjective' kind. The surveyor was asked 'to score the area appearance, considering the area with respect to the four attributes already scored'. Thus an intuitive, unconscious and instinctive weighting and aggregation was made, through which such factors as interactions between the attributes (see SOUTH YORKSHIRE COUNTY COUNCIL 1978b) would be taken into account, although in an unspecified manner not necessary repeatable by another observer, or by the same observer in a different situation.

As a whole therefore the operational method is seen to involve a certain amount of observer subjectivity as a necessary and inevitable part of the measurement process, and the relatively less quantitative characteristic of the method, compared with the precise, quantitative expression of the description statements in the Civic Trust method, means that the method of this research is relatively more susceptible to observer subjectivity. There are advantages in this:

(i) The method is quicker;

(ii) Intangible, qualitative characteristics of areas may be included in the evaluation;

(iii) Interactions and variations in measurement and weighting are intuitively taken into account by the surveyor;

(iv) The mathematical problems of weighting, and aggregating ordinal data are avoided.

However, as stated in the review of the methods using direct measures of individual response, the inclusion of subjectivity in the measurements reduces the repeatability of the method. In the method of this research subjectivity can affect repeatability by entering the measurement process in two stages, firstly in the scoring of individual attributes, and secondly in the aggregation and scoring of the overall area quality. Clearly therefore it is necessary to examine the significance of these elements of subjectivity in terms of their effects on the repeatability of the method, and this is done as part of the statistical analysis in the following section 7.3.2. More generally it may be noted that the method of this research is much less susceptible to the effects of subjectivity than the measurements of individual response, because the intrinsic features of the operational method include objective criteria, viz:

(i) An explicit identification and definition of the component attributes of area appearance to be assessed;

(ii) The use of 'description statements' to characterise each discrete 'score' unit in the measurement system.

A more general appraisal of the measurement method in relation to the criteria of relevance, repeatability and discrimination is made at the end of the section.

7.3.2 Statistical Analysis of the Measurement and Sampling Methods

This section discusses the results of five statistical tests which were made upon the measurement and sampling methods.

The first of these concerned an investigation of the degree of co-variance between the four component attributes of area appearance. The interest in covariance stemmed from the fact that the significance of the whole problem issue surrounding the weighting and aggregation of component attributes is minimised where the attributes exhibit covariance (as described in some detail in Chapter 8).

For ordinal data the non-parametric test for covariance is made on the Kendall Coefficient of Concordance, w, using in this context the null hypothesis that the measurements of each attribute were mutually independent. From the data obtained in the survey Phase 1, 95 separate observations of the four attributes were available. The test of concordance followed the procedure described by SIEGEL (1956), and involved ranking the 95 measurements of each attribute, then for each of the 95 measurement sites, adding the relevant four attribute ranks to give the Kendall 'sum of ranks' parameter R_j where j = 1,95. The value of w was calculated according to the relation

$$w = \frac{\sum_j (R_j - \bar{R}_j)^2}{\frac{1}{12} k^2 (N^3 - N)} \qquad 7.2$$

(SIEGEL 1956)

where k = no. of indicators = 4, N = no. of samples = 95, and $\bar{R}_j$ is the mean value of R_j. After correcting for tied values using the standard method given by EDWARDS (1964), a value $w = 0.805$ was obtained. The significance of this value may be tested either by the Chi-square test or the F-test, as described by SIEGEL (1956). The equivalent Chi-square value was 302.7; at the appropriate 94 degrees of freedom Chi-squared is significant at the 1% level for values exceeding 50.9. The equivalent F-value was 12.38; at the appropriate 93.5 and 280.5 degrees of freedom F is significant at the 1% level for values exceeding 1.45. The tests both indicated therefore that there was considerably less than a 1% chance that the observed degree of concordance between the four sets of attribute measurements could have occurred by random statistical chance. Consequently it was concluded that the attributes were significantly concordant, and that (since the samples constituted a spatially comprehensive sample frame) that the attributes were significantly covariant over space.

The Kendall 'sum of ranks' parameter R_j was then used in a test of the aggregation procedure. This was made possible by the fact that the 'sum of ranks' parameter is in itself a non-parametric 'best estimate' of the aggregate effect of the four ranked sets, with assumed equal weightings (SIEGEL 1956, EDWARDS 1964; see the more extensive discussion of this point in relation to the study of aggregate environmental indicators). It was thus possible to compare two aggregate rankings of the 9 5 observed locations; the first obtained through the ranking of the 'area appearance' measures resulting from the intuitive method as described in section 7.3.1, and the second through the non-parametric 'sum of ranks' aggregation R_j. The correlation between the rankings was tested through the standard non-parametric test for correlation between two ordinal measures, the Spearman Rank Correlation Coefficient r_s, calculated according to the relation

$$r_s = 1 - \frac{6 \sum_j d_j^2}{N^3 - N} \qquad 7.3$$

(EDWARDS 1964)

where d_j = difference between the two rankings of the j^{th} observation, and

N = total no. of observations = 95. After correcting for tied values using the standard method given by EDWARDS (1964) a value of $r_s = 0.972$ was obtained. The significance of this value of r_s may be tested through application of the t-test (SIEGEL 1956) upon the equivalent t-value of 39.6. For the appropriate 93 degrees of freedom t is significant at the 1% level for values in excess of 3.37; consequently the null hypothesis of no relationship between the two rankings must be decisively rejected. It was therefore concluded that a very strong correlation existed between the area appearance scores obtained by the operational measurement method already described and the available 'best estimate' of the concordant effect of the four component attributes. Thus it is evident that while no explicit weighting and aggregation procedure was proposed in the operational measurement method for determining area appearance scores, the method produced results which are strongly correlated with a more explicit ordinal aggregation technique with assumed equal weighting of the attributes.[1]

The results of the above tests serve to enhance the confidence which may be held in the repeatability, validity and reliability of the measurement methodology itself. In operation however the method rests upon the 'representativeness' of the individual surveyor's scoring of locations examined over a period of less than an hour. The representativeness of the results may be examined with respect to two sources of sampling error. Firstly, the surveyor's own evaluation may have changed over time; this could occur, despite the general constancy of the visual aspects he observes, as a result of innate shifts in the personal evaluation mechanism over time, and more particularly over the six-month period during which surveying took place as the surveyor became familiar with using the measurement method.

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1. It will be seen in the discussion in Chapter 8 that the existence of concordance between attributes minimises the relevance of their individual weightings.

Secondly of course the surveyor is but one individual respondent, and for the method and results to be presented as of general usefulness it should be established that the results obtained from the single surveyor's evaluation are acceptably representative of some consensus evaluation.

The former source of error was tested through an analysis of the results of the survey Phase 3, involving a return visit to seven sample TAEs, compared with the results obtained at the time of the first survey some 2-6 months earlier.[1] This comparison is achieved through the cross-tabulations shown in Fig. 7.3. These show that the data for the 35 locations involved are strongly correlated and it was not considered necessary, in view of this clearly evident relationship, to make a statistical validation of it. Rather than a test of the strength of the relationship the desired statistical description of the relationship is the error of estimate; that is, the error in using a given observed score as a representative figure for that location. Owing to the non-parametric nature of the data however such a descriptor cannot be obtained since ordinal score differences cannot be pooled to give any meaningful statistic such as a 'standard error'. It is possible only to give data describing the results of the empirical comparison; thus the cross-tabulations in Fig. 7.3 are accompanied by diagonals which delineate the band of observations exhibiting differences of 1 score or less, from which it may be observed that in the case of the overall area appearance scores for sample locations, only five (14%) of the 35 samples show differences of more than one score value. It is also seen that these results are typical of the four component attributes.[2]

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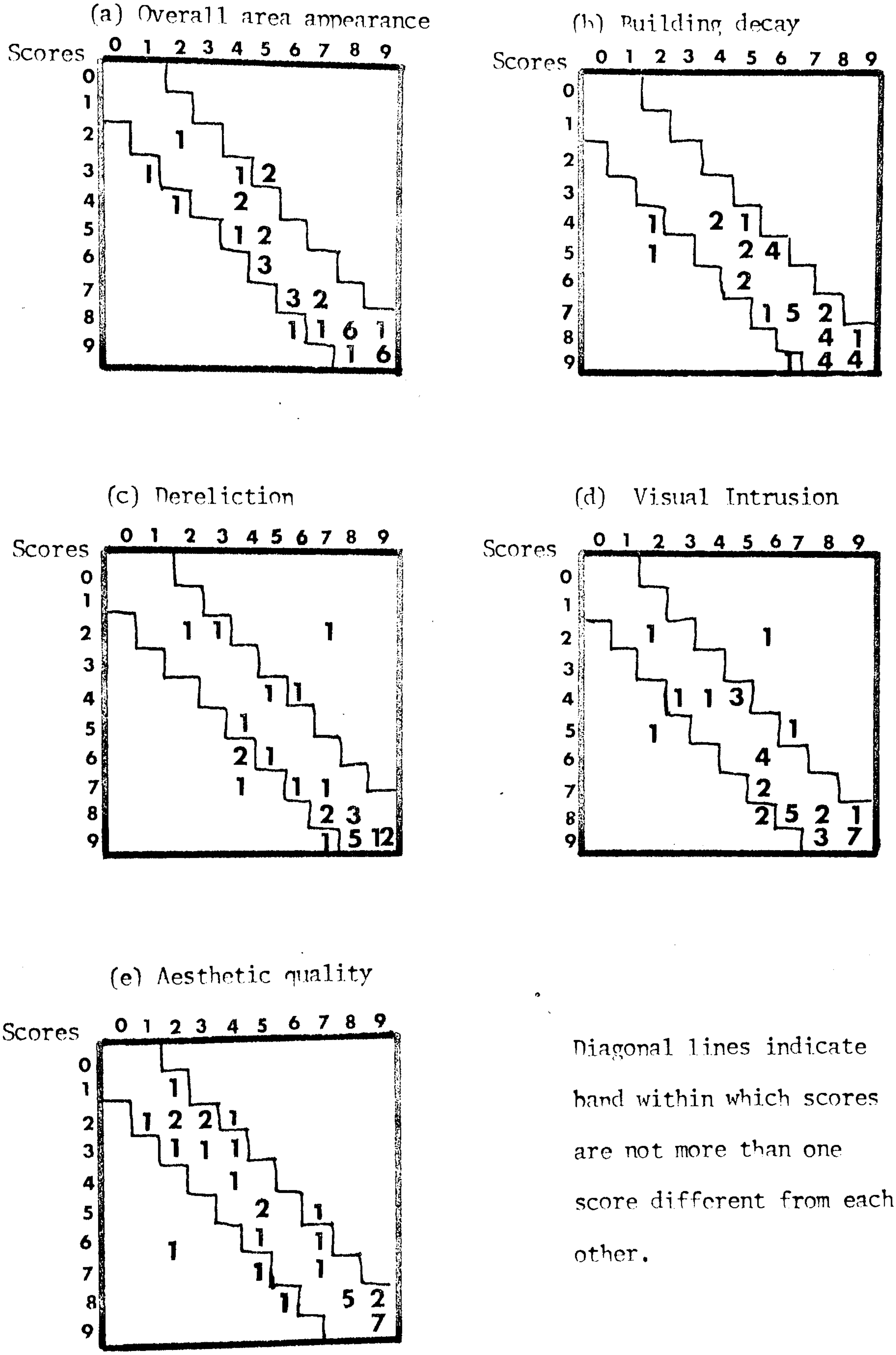
1. It was assumed that such a time interval would obviate the possibility of the surveyor remembering at the time of the second survey the score he made on the occasion of the first visit. This was indeed the case, so far as the surveyor was consciously aware.

2. Note that it is invalid to infer from this that a 14% possibility exists of two area appearance scores for the same location being more than 1 score value different.

Fig. 7.3 Cross-tabulation of frequency of area appearance scores observed on two separate occasions (at the location level).



Diagonal lines indicate band within which scores are not more than one score different from each other.

The most desirable method for examining the representativeness of the individual surveyor's evaluations would be to compare his results with those obtained from a number of other surveyors. Within the scope of this research such a study was not feasible and in any case the best available test was to compare the area appearance scores with those obtained from another similar operational method. Thus if a consistent relationship between the results is attained, and the repeatability of one method has been validated, it may be inferred that any subjectivity in the other method does not detract from its repeatability.

It has been seen that the most appropriate alternative method to that used in this research is the method developed by Buchanan (BUCHANAN C. 1971, BUCHANAN J. 1973). There are however limitations in its use as a comparable method, firstly since it was developed to apply specifically to residential environments, and secondly because the aspects of area appearance that it is designed to reflect are not identical to those used in the method of this research. In fact it is a method of classifying residential environments on the basis of a range of factors describing socioeconomic and environmental qualities of which those most directly comparable to this research are building age, building condition and upkeep, private open space condition and the conditions of neighbouring land. In a case study context (VOORHEES and ASSOCIATES 1973) the method was used on ten categories or 'clusters' of area type (given in Table 7.8) to obtain a mean 'deficiency score' for each category (the resulting cumulative frequency distribution is shown in Fig. 7.4). The interval properties of such a scoring system are questionable and it was felt to be more realistic to take the deficiency scores of the Buchanan case study simply as a method for making an ordinal ranking of the ten Buchanan categories.

The comparative study required minor modifications to be made to the Buchanan system. A new 'not applicable' category, code '0', was introduced

Table 7.8 Clusters of Housing Areas Defined in Terms of Main Characteristics

Cluster 1

Pre-1914 terraced housing with poor household amenities, rented unfurnished with some 'flat terraces'. High densities and poor outlook.

Cluster 2

As cluster 1, but with a much higher proportion of 'flat terraces' and higher densities. More dwellings occur in clearance programmes.

Cluster 3

Pre-1914 terraced housing, lacking some basic amenities, and with a high proportion of owner occupation. A large number of people aged over 65 living in small households at a low room occupancy.

Cluster 4

Pre-1914 terraces, with a high proportion of dwellings converted into flats, providing furnished accommodation. These contain a large number of one-person and sharing households with a high proportion of professional workers.

Cluster 5

Areas of semi-detached housing a large proportion built between the wars, with no flats or unfurnished dwellings. Household amenities are good, room densities low and middle-aged people predominate, often in 2-person households.

Cluster 6

Areas of high room occupancy on council estates built post-1914. Blue-collar workers, a large proportion unskilled, and relatively low levels of car ownership.

Cluster 7

Similar to cluster 6, but with a high proportion in post-1945 council flat blocks to which the occupants have moved from other parts of the local authority in the last five years.

Table 7.8 (Continued)

Cluster 8

White-collar workers living at low room densities in owner-occupied houses, often built between the wars, with a garaged car. Few young children, and high proportion of residents aged over 45, often in 2-person households.

Cluster 9

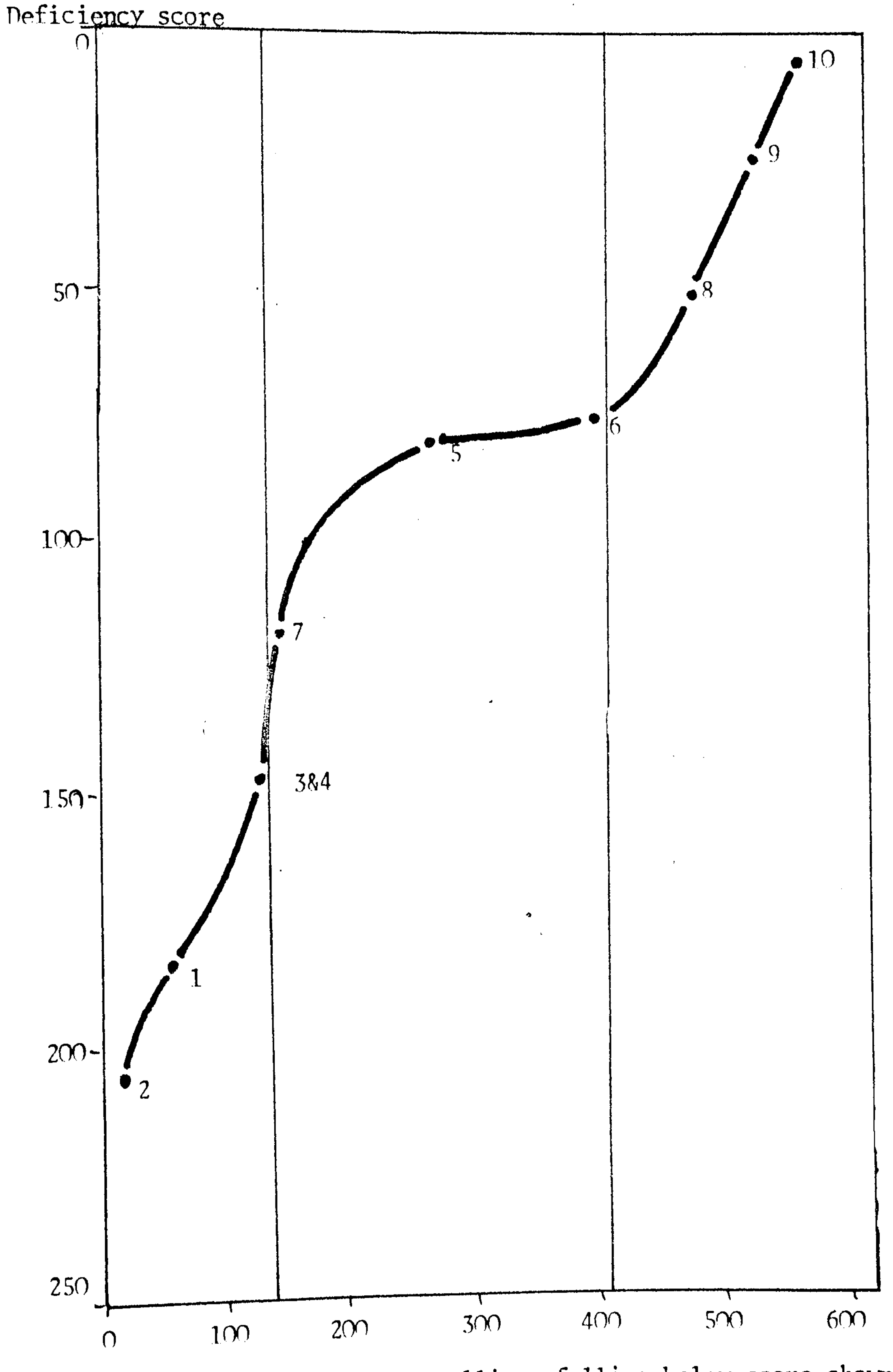
Similar to cluster 8, but with a more even balance in the age of the population, and more post-1945 housing.

Cluster 10

Housing located at some remove from town centres, and not well served by public transport, but with very good outlook. A large proportion of semi-skilled manual workers in houses of miscellaneous tenure and a large number of detached dwellings.

[The measurement of housing condition in the surveys used a deficiency points scoring system relating both to the housing unit itself and to the local environment. The features that were measured included, for example: dwelling structure, maintenance, rear space and front space; interior facilities and amenities; exposure to external traffic noise, presence of off-street parking; traffic in street; residential density; landscape quality, and children's play areas.]

Fig. 7.4 Predicted 'deficiency scores' for Buchanan code area types (Source: Buchanan 1971)



as a 'null score' for those locations where the Buchanan method could not be used (i.e. where there were no houses); this applied to approximately one location in three. Categories 9 and 10 were therefore combined to maintain a ten-point 'measurement' scale. In survey phases 1 and 2, each of the 150 locations was allocated a Buchanan code (0 to 9) in addition to an area appearance score as already described. Fig. 7.5 shows a cross-tabulation

Buchanan Code (ranked)

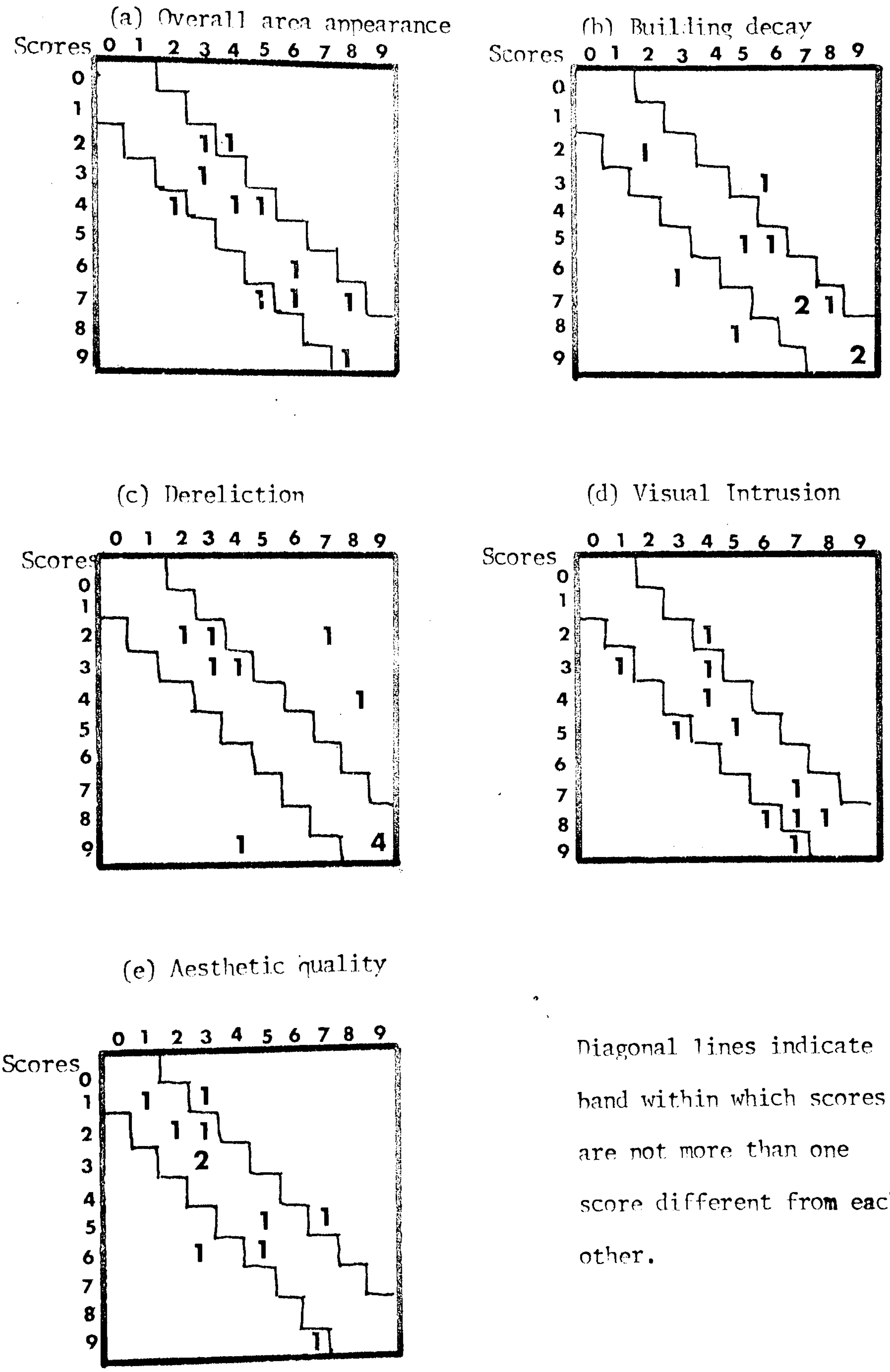
Area Appearance (Scores)	0	2	1	3	4	7	5	6	8	9
0	3		1							
1	2	1	2	2						
2	5		5	3				2		
3	13		5	5			1	1		
4	7		2	3	2	2		4		
5	2		3		1	1	1	6		1
6	3					1	4	5	2	
7	3					1	9	3	2	1
8	7					1	6	1	6	3
9	3								3	

Fig. 7.5 Cross-tabulation of Buchanan code categories against observed area appearance scores.

between the area appearance scores and the Buchanan codes, the codes ordered according to the ranking derived from Fig. 7.4. The relationship between the area appearance scores and the ranked Buchanan codes is clearly evident; it should also be noted that the 'not applicable' Buchanan code 0 was approximately independent of area appearance, and could therefore be discounted as a possible cause of spurious relationship. The relationship was tested by the Spearman Rank Correlation Coefficient r_s, with the Buchanan code 0 eliminated from the data. A value of $r_s = 0.36$ was obtained after correction for ties, equivalent to a t-value of 3.86. For the appropriate degrees of freedom t is significant at the 0.1% level for values exceeding 3.25, and therefore the relationship was validated at this significance level. This result may be interpreted as showing that a significant relationship exists between the two measurement methods. From this it may be inferred that the element of subjectivity present in the operational method of this research does not seriously affect the repeatability of the method, since a clear correlation with an established, repeatable measurement method is achieved.

A final analysis of the data was made to test the amount of variation existing between the median area appearance scores of TAEs of the same type. The results of this analysis have already been referred to in section 7.2.2, where it was stated that the survey phase 2 provided a method for comparing the median scores of eleven samples of two TAEs of the same type. The resulting comparisons are illustrated in the cross tabulations in Fig. 7.6 for the overall area appearance scores and those for the four component attributes. As in the cross tabulation of the scores obtained on different occasions, the parameter of interest (the error of estimate in using a single TAE median to represent the median score for all TAEs of the same type) cannot be obtained due to the ordinal nature of the data. Once again diagonals are used to illustrate the frequency with which differences exceed one score value, and it may be observed that in the case of overall area appearance only three (24%) of the eleven samples showed median differences of more than one score value, and none of more than two score values; these results are also typical of the attribute scores, and were all that could be used to conclude that the attribute scores,

Fig. 7.6 Cross-tabulation of frequency of median area appearance scores for two TAEs of the same type.



Diagonal lines indicate band within which scores are not more than one score different from each other.

variations between TAEs of the same type did not contribute significantly to the observed differences between the TAEs that were used to test the TAE hypothesis, sampled from different types.

A detailed discussion of the operational method for measuring area appearance has been conducted in this section. As a result of this it may be concluded that the method is more relevant to the needs of this research than the other types of method used in contemporary studies, namely the direct measurement of individual response and the simulation models of the stimulus/response relationship in the individual respondent. The adequacy of the operational method may be assessed with respect to the criteria laid out in section 7.1.2:

(i) Relevance to the context It has been seen that the method incorporates the measurement of attributes that affect the individual's response to the visual condition of an area, and that planning policies seek to or inadvertently affect or involve; this is evidenced by their inclusion in other contemporary studies.

(ii) Repeatability The objective criteria, used (a) to explicitly identify and define the four component attributes, and (b) to formulate specific 'description statements' appertaining to each discrete 'score' unit in the measurement scales, serve to reduce the amount of observer subjectivity incorporated in the method. The subjectivity intrinsic to the aggregation and overall appearance scoring has been seen to be minimised by the presence of covariance between the attributes, and the finding of a correlation between the statistical 'best estimate' of the combined equal-weighted effect of the attributes and the field-measurement of overall area appearance. The method has been shown to be repeatable over a time period of 2-6 months and correlates with a method based on similar objective criteria but conducted by other researchers.

(iii) Discrimination The method has been shown to produce results that discriminate between the appearances of different types of area. It therefore provides an adequate basis for the testing of the TAE mapping methodology.

The section has also presented other statistical tests relevant to the testing of the TAE hypothesis and estimating the accuracy of the TAE prediction model. Despite the need for non-parametric statistical analysis it has been shown that for the most part it is possible to conduct an analysis that is adequate for the purposes of this research.

7.4 APPLICATION OF THE TAE PREDICTION MODEL AS A MAPPING METHOD

The TAE methodology was tested in respect of its third objective, as a mapping method. Essentially the procedure was identical to that adopted in the case studies already described, involving the grouping of TAE types into five categories, and the mapping of the predicted pattern of these five categories from an urban fabric data input consisting of a map of TAEs. However the ordinal properties of the data require a modified approach to the problem of grouping.

7.4.1 Grouping the TAE types, and Nature of the Resulting Categories

Unlike the previously-discussed case studies it was not possible to use the 'significant gap' parameter to show the statistical requirement for grouping. Nevertheless the data appertaining to the TAE prediction model, given in Table 7.7, shows that grouping is statistically necessary simply because several TAE types share identical predicted median area appearance scores. There is of course a need for the 'five category' grouping on the grounds of display factors alone, as described in Chapter 3.4

The fact that the median scores in Table 7.7 show comparatively little numerical variation means that a 'natural grouping' approach to categorising the distribution of the median scores is of little use since median scores do not discriminate strongly between the TAE types. It was decided therefore to use the discrimination achieved by the 'sum of ranks' parameter, R_j. As was seen in Table 7.6 and discussed in section 7.2.3, this parameter shows considerable numerical variation between TAE types and is a better discriminator than the median score. Despite its apparent ratio properties however it should be noted that the R_j parameter may only be interpreted as a means to obtaining a <u>ranking</u> of a set j (KENDALL 1948, cited in SIEGEL 1956). The numerical intervals between R_j values may not therefore be used to indicate the relative magnitudes of differences between the area appearances of the TAE types. However it is evident that the numerical magnitude of the difference between two successive R_j values is an indication of the degree of confidence that may be held, on the basis of the data from which each was derived, in the allocation of a rank discrimination between the data sets in preference to an equal or 'tied' ranking. Considering three examples from Table 7.2 to illustrate the point, it is evident that (a) no confidence whatever exists in the discrimination between categories 4A and 6A, since their R_j values are identical; (b) little confidence may be held in the ranking of category 1A above category 0A, since their R_j values are very similar; (c) a high degree of confidence exists in the ranking of category 6A above category 8B, since their R_j values are numerically very different. Thus it was held that the numerical distribution of R_j values <u>could</u> be used as a method of seeking for natural 'breaks' in area appearance conditions as a basis for a natural grouping approach, just as natural 'breaks' in the sulphur dioxide distribution were used to group TAEs, but the rationale for doing so was based on the degree of confidence in the rankings rather than numerical (interval) differences in predicted conditions.

Table 7.9 shows the five groups obtained by applying this approach

Table 7.9 Grouping of TAEs: Predicted Area Appearance Scores and 'Sum of Ranks' Ranking

Group	TAE Type	Predicted Median Area Appearance Score	Kendall 'sum of Ranks' R_j and ranking		Median Area Appearance ranges in Groups	% of WMMC Area in Groups
1	6B Ind/Comm/Medium	2	69	1	Below 3	5.4
	4A Res/Ind/Dense	2	79.5	2=		
	6A Ind/Comm/Dense	2	79.5	2=		
2	8B Ind/O.S./Medium	3	115	4	3 to 4	16.0
	8C Ind/Sparse	3	123.5	5		
	1B Industrial/Medium	3	130	6		
	4B Res/Ind/Medium	4	157	7		
	1A Industrial/Dense	4	180	8		
3	0A Residential/Dense	5	186.5	9	5 to 7	13.3
	2A Commercial/Dense	6	233	10		
	5B Res/Comm/Medium	5	240	11		
	5A Res/Dense	7	326	12		
4	0B Residential/dense	7	236	13	7 to 8	42.1
	7C Res/O.S./Sparse	8	351	14=		
	5C Res/Comm/Sparse	8	351	14=		
	7B Res/O.S./Medium	7	352	16		
5	7A Res/O.S./Dense	8	371.5	12	8 to 9	23.2
	0C Residential/Sparse	8	409	18		
	3C Open Space/Sparse	9	437.5	19		

allied, as in the other studies, with a further criterion that a distinctive urban fabric identity to the groups be maintained, wherever possible. The nature of these groups is discussed in section 7.4.2 following. Chapter 6.5.1 included a discussion of some of the issues involved in making comparisons between the values of different indicators, and the discussion referred to the advantage of making comparisons with respect to a scaling system (in this case, the 'five category' grouping) with equal land area proportions in the equivalent categories of each indicator. While there is no necessity for such a condition to result from the criteria used to group the three indicators examined in this research, it is of interest to note from Table 7.9 that, with the possible exception of groups 3 and 4, the proportional distribution of the WMMC land-area between groups is quite comparable with that obtaining in the groupings of the other indicator prediction models; this point is discussed further in Chapter 8.

Table 7.9 constitutes the 'grouped' or aggregated version of the TAE prediction model and it was applied as a mapping method in a manner identical to that adopted in the previous studies. The resulting maps are shown in Figs. 7.7 and 7.8, the former showing the pattern obtained for all five groups and the latter that for the 'stress' (group 2) and 'high stress' (group 1) areas only.

7.4.2 Discussion of the Mapped Data

The urban fabric composition of the five 'groups' may be seen to be broadly similar to the groupings obtained in the other case studies, but with some notable exceptions. Group 1 is typically the smaller commercial and industrial towns in the conurbation (especially predominant in the Black Country) and the 'inner city' zones, represented in the mixing of industrial activities with commercial and residential land use in areas where the road network density is high; the identity of this group as of the poorest area appearance is probably related with the general age of the

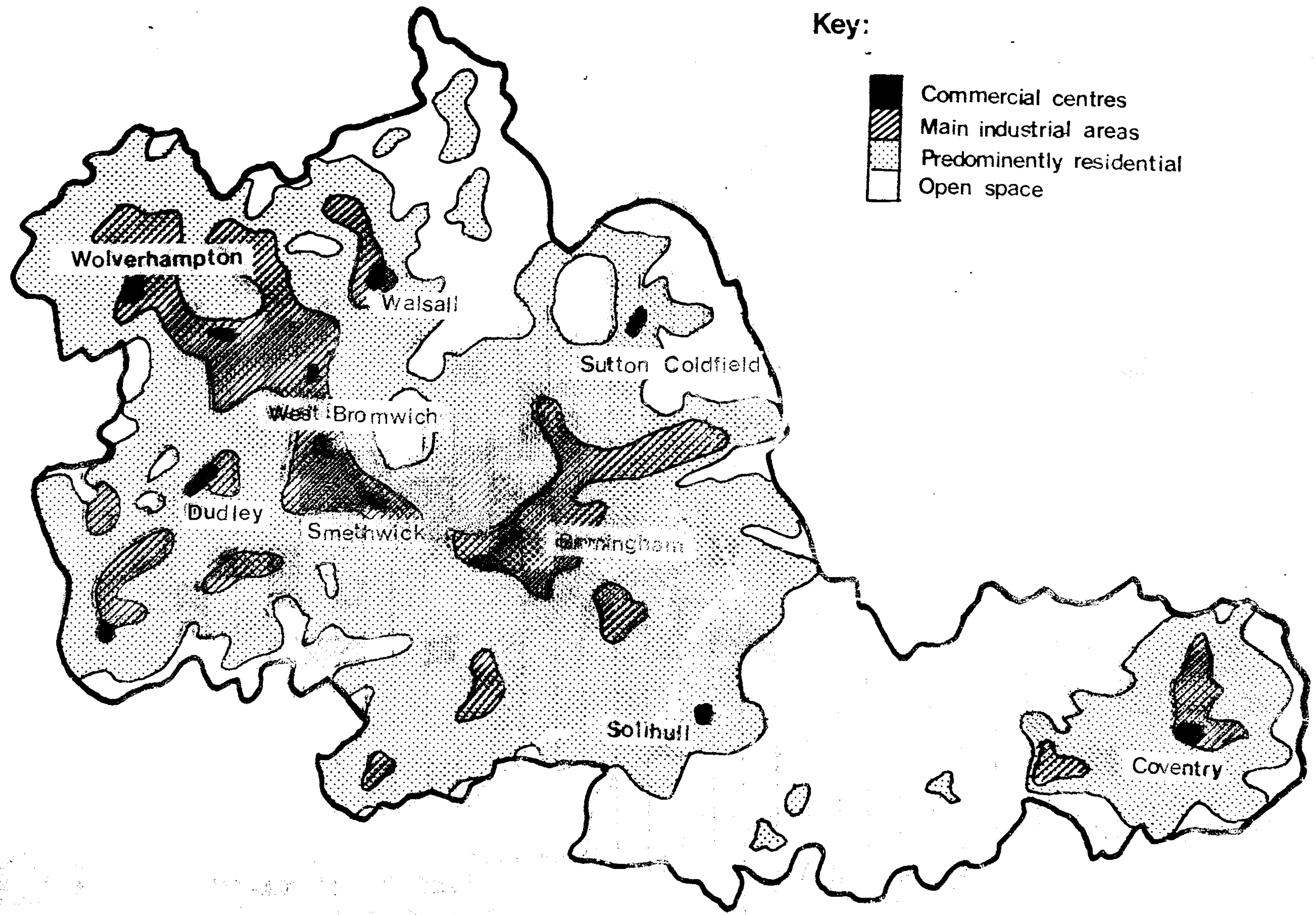


Fig. 7.7 Map showing predicted area appearance conditions in the WMC

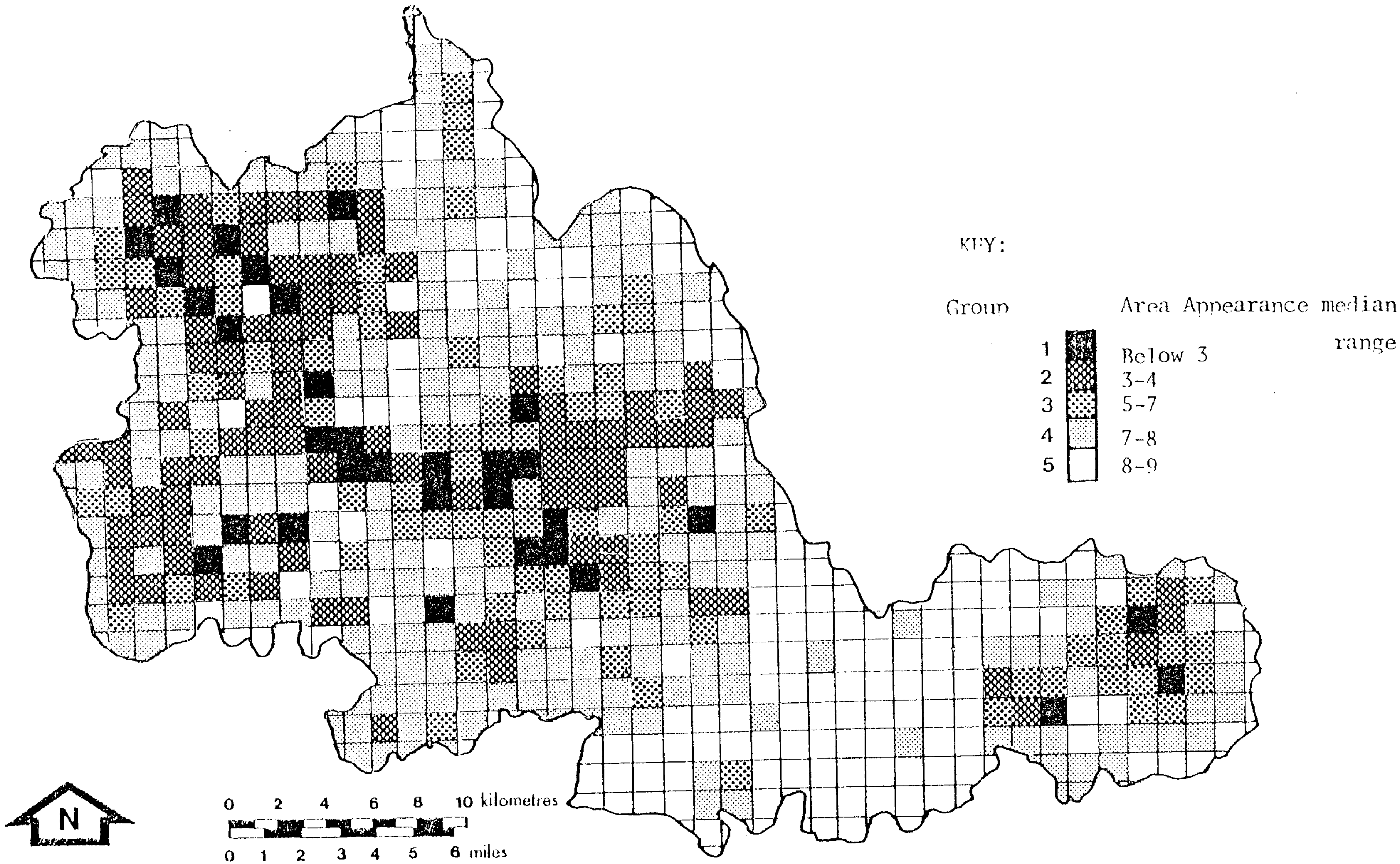


Fig. 7.7 Map showing predicted area appearance conditions in the WMMC

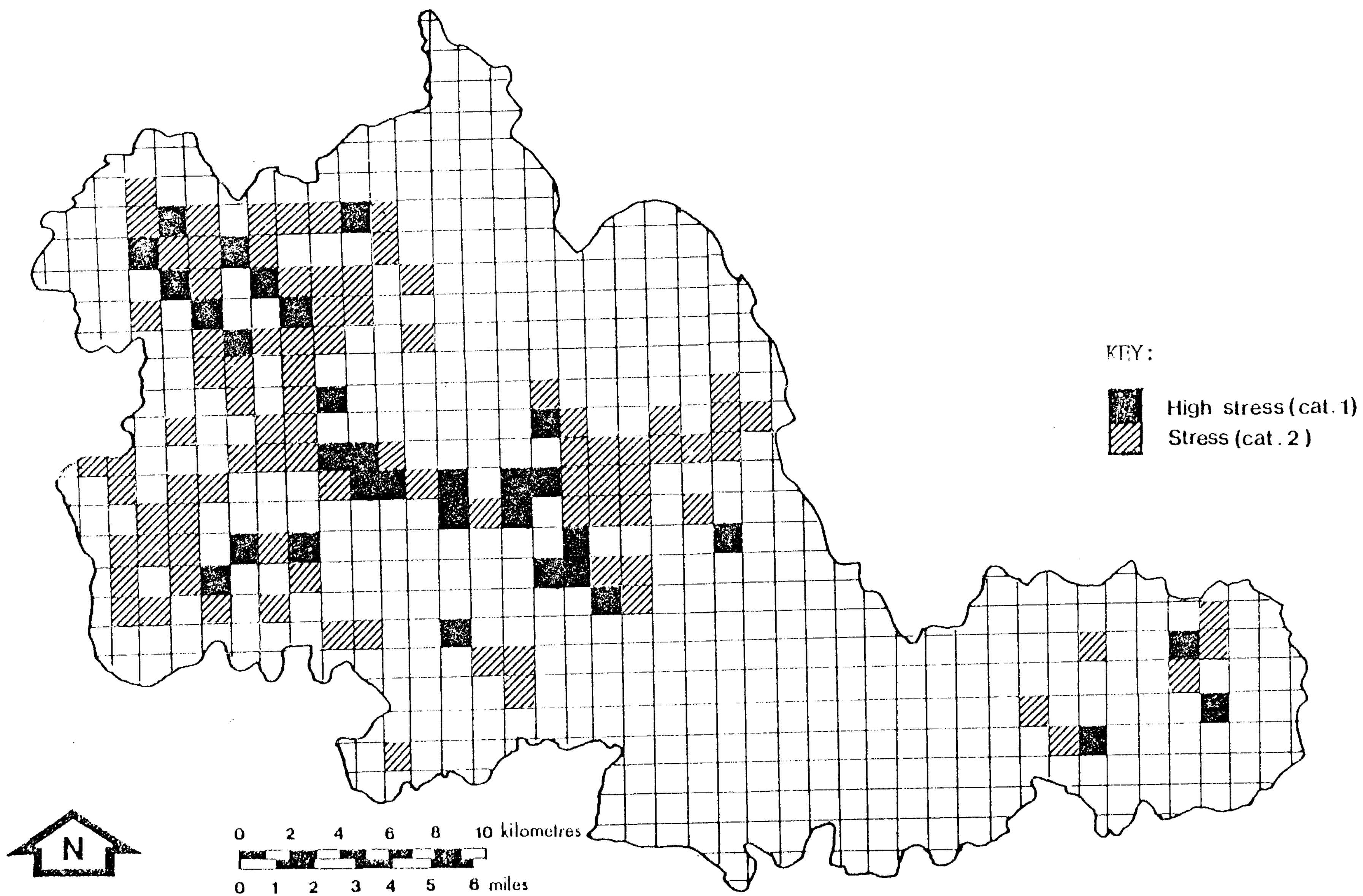


Fig. 7.8 Map showing the location of 'stress' and 'high stress' areas in the WMMC

built form, since these types of area were commonly constructed in Victorian times and are now in disrepair. Group 2 contains all remaining categories where industry is present; it thus shares an identity with the group 2 characteristics of the other studies except for the inclusion of areas where lower density industry is mixed with open space - in the previous studies such areas were found in group 4. Group 3 includes most of the commercial areas, including the large city centres (category 2A) which were found in Group 1 in the previous studies ; the distinct urban fabric identity, of a commercial nature often associated with high density residential areas, was the reason for allocating categories 0A and 5A to this group despite the R_j 'breaks' implying their association with groups 2 and 4 respectively. The greater part of the residential area of the conurbation falls into group 4, while group 5 consists of the rural and semi-rural areas on the fringe of the conurbation, but also includes the suburban residential area (7A) in the vicinity of parkland and golf courses where area appearance is also high.

These characteristics are illustrated in the maps shown in Figs. 7.7 and 7.8. The general association between area appearance conditions and the pattern of predominant land use types is evident, but the relationship differs noticeably from that of the previous case studies as seen by the fact that the 'stress' and 'high stress' areas centre on the smaller industrial towns of the 'Black Country' and the inner city 'ring' around Birmingham, rather than the larger city centres as was found to be the case in the studies of ambient noise and sulphur dioxide air pollution.

7.5 COMPARISONS AND CONCLUSIONS

The case study described in this chapter is appraised firstly through a comparison of results, and secondly through a summary of the methods, a comparison with those of other approaches, and conclusions.

7.5.1 Comparison of Results with Those of Other Studies

It is difficult to make a meaningful comparison between the results of the research case study and the results of other equivalent studies, because of the non-standardised nature of the concepts and data concerned and the ordinality of the data. It has been stated that the Buchanan classification system is the most comparable contemporary technique and by actually taking Buchanan-code 'measurements' simultaneously with area appearance it has been possible to make a direct statistical comparison of the results of the two methods. Table 7.10 shows that the ranking of

Table 7.10 Ranking of Locations by Buchanan Code and Medium Area Appearance

Buchanan Code	Buchanan Rank	Observed Median Area Appearance Score	Area Appearance Rank
2	1	1	1
1	2	3	2=
3	3=	3	2=
4	3=	4	4
7	5	5	5=
5	6	7	7
6	7	5	5=
8	8	8	8=
9	9	8	8=

locations according to the Buchanan system is almost identical to the ranking obtained by ordering the median area appearance score appertaining to each Buchanan code; it may therefore be asserted that both classification systems are broadly comparable in their ranking of the visual condition of the physical properties of areas.

7.5.2 Summary, Comparisons and Conclusions in Relation to the TAE Mapping Methodology

The case study of area appearance has involved as much discussion of the measurement method used as of the testing of the TAE mapping methodology itself. This degree of emphasis on the measurement issue was made necessary by the need to develop an 'operational' concept of area appearance which was appropriate to the demands and context of this research. This concluding section considers firstly the three objectives in the testing of the TAE methodology, and then summarises the main conclusions in relation to the operational measurement system to which the methodology was applied (a detailed account of the conclusions was made in section 7.3).

(a) The test of the TAE hypothesis

(i) The test of the hypothesis showed that a statistically significant relationship exists between the TAE type of zones and their observed area appearance. This conclusion was reached as a result of conducting the non-parametric Kruskal-Wallis H-test upon sample data obtained from examples of each TAE type. The H-value of 36.3 was significant at more than 99% confidence.

(ii) The intuitive rationale for expecting to find a relationship between area appearance and urban fabric characteristics is stronger than in the cases of ambient noise and sulphur dioxide air pollution, in that area appearance as measured in this research is essentially a direct function of the urban fabric condition (this is particularly evident with building decay and dereliction).

(iii) The principle of the TAE classification system is essentially no different from that of the Buchanan coding system, which also attempts to classify areas into categories of condition. It is not therefore a unique approach but it is more comprehensive in the types of area covered by the classification (a fact made possible by the comprehensive measurement method).

(b) The TAE prediction model

(i) The model predicts the median area appearance scores of each TAE type, on the same basis as the parametric models' equivalent use of the mean value, adopted in the two previously-discussed case studies.

(ii) In principle the model is essentially the same as that used by Buchanan, except for Buchanan's assertion that interval-scale 'deficiency score' data may be obtained; the properties of the area appearance data are quite definitely ordinal.

(iii) The error of estimate of the model cannot be directly assessed owing to the ordinality of the data; instead an appraisal of its accuracy is made simply upon the basis of the observed distribution of predicted to measured scores, and this limited evidence indicates that the results are sufficiently reliable for the model to be used as a 'five-category' mapping method.

(c) The TAE Mapping Method

(i) The mapping method involves the familiar 'five category' grouping of TAEs, with the grouping being performed upon the Kendall 'sum of ranks' parameter R_j to enable a more precise discrimination between TAE types to be achieved than would have been possible simply on the basis of the predicted median scores; the groups are equated to median score ranges however in order to make the choropleth map meaningful in terms of area appearance conditions.

(ii) The mapping method is in principle conceptually identical to the other mapping methods in contemporary research which use the assessment of independent, physical variables in order to predict the condition of qualitative factors (SOUTH YORKSHIRE COUNTY COUNCIL 1978b). It has the advantage over the direct response measurement studies (e.g. FINES 1968) in that an extensive zone-by-zone measurement process is avoided, yet the concomitant disadvantage is that the accuracy of the mapped zone conditions is less reliable; this is of course a general characteristic in the comparison of measurement based and predictive mapping methodologies (see Chapter 9).

(d) <u>The operational method for measuring area appearance</u>

(i) Three types of approach may be used in measuring area appearance: direct measurement of individual response; prediction of individual response by a 'simulation model' of the stimulus/response process; and operational methods for classifying areas based on certain visual characteristics of their physical fabric. The operational method was used in this research because it is readily applied, and the first two alternatives show poor repeatability and dubious theoretical validity respectively.

(ii) The operational method used in the research was seen to be relevant to the study context, for the following reasons: the component attributes are known to effect human response; they have been used in other equivalent studies; they are factors that are affected by or are of interest in public planning; and the attributes are defined in such a way that they are ubiquitously measurable for the case study area.

(iii) The method incorporated elements of observer subjectivity because an individual surveyor was used essentially as part of the 'measurement tool'. The extent of subjectivity in the method was limited by the use of operational criteria, firstly in the identification and definition of the 'operational' component attributes of area appearance and secondly in the formulation of specific 'description statements' appertaining to each measurement score. Furthermore the significance of subjectivity in the 'aggregation' procedure was minimised by the finding that the four attribute measures were concordant, and that their statistical 'best estimate' ranking correlated with the field-measurements of overall area appearance. It was found that the repeatability of the method, which might have been constrained by the subjective elements, was adequate for the purposes of the research.

(iv) The method was found to produce results that discriminated between the area appearances of different types of area. The method could therefore be used as a basis for testing the TAE methodology.

As with the earlier case study Chapters 6 and 7, broader issues arising from this case study that concern the general adequacy of the TAE methodology are addressed in the concluding Chapter 9. A comprehensive account of the case study results is given in Appendix D, in which the predicted area appearance conditions of the TAE types may be compared with other environmental and general descriptive data.

CHAPTER 8

CASE STUDY OF AGGREGATE ENVIRONMENTAL CONDITIONS

8.0 INTRODUCTION

This chapter discusses the fourth empirical case study, which involved the aggregation of the three attribute indicators already described and the mapping of the resulting 'aggregate environmental conditions' indicator using the TAE methodology. The chapter is shorter and more cautious in approach than the other case study chapters and the emphasis is on a discussion of the problem issues rather than on the detailed analysis of empirical data. There are several reasons for this. Firstly, no new data were introduced in the case study. In addition, the case study is intrinsically limited as a means of discussing general environmental aggregation problems because only three component environmental attributes could be treated empirically, and in any case the range of environmental attributes that may be approached through the TAE methodology is itself limited. Furthermore the methodological issues surrounding environmental aggregation (including also the questions of scaling and weighting component indicators) are complex and open to some controversy, and an extensive analysis is beyond the scope of this research.

8.0.1 Empirical Research Method

(a) Aims and objectives The chief aims of the case study were to examine the issues involved in the aggregation of environmental indicators particularly where some at least are only measurable in terms of ordinal data, and to test an ordinal aggregation and mapping method using the TAE methodology. The usefulness of indicator aggregation has already been discussed in the particular case of area appearance, and in the more general environmental context the aggregation is relevant in a number of circumstances: where there is a need to represent a convenient abbreviation of several data sets; where it is desirable or appropriate to consider the effects of several attributes acting as a whole; and in cases where indicators are highly spatially covariant (and therefore where the pattern of one indicator alone may be used as a 'key indicator' of the pattern of the covariant set). These are useful means of summarising environmental data for the more general planning contexts - such as intra- and inter-regional comparisons for budget allocation, and general environmental statements such as 'State of Environment Reports' where the environmental pattern is compared with other data and general trends in environmental conditions are assessed.

The particular empirical objectives of the study were to develop an ordinal aggregation method and to test the TAE mapping method through the familiar three stages: hypothesis testing, TAE model calibration, and application of the model as a mapping method. It will be seen that the aggregation method used was dependent upon the existence of a spatial covariance between the component attributes, which it was also therefore necessary to test. The data upon which the objectives were tested derived from the TAE prediction models of the three attribute case studies.

(b) Hypotheses, tests and methods The key hypothesis in the case study was the assertion that the three component attributes were spatially covariant. This hypothesis was effectively equivalent to the TAE hypothesis for an aggregate indicator, for its validation dictates that any aggregation of the component attributes, however weighted and aggregated, must necessarily be significantly variant with TAE type because each component attribute has itself already been found to show a significant relationship with TAE type. The test for covariance was the Kendall Coefficient of Concordance, and it will be shown that in cases where significant concordance exists the 'Kendall best estimate of ranks' parameter R_j (the distribution of which forms the basis of the hypothesis test) may be interpreted as an ordinal aggregate indicator from which a TAE prediction model and mapping method may be derived, through the same kind of non-parametric approach as that used in the area appearance study. Thus it is evident that the testing of the hypothesis of covariance is the most crucial analytical aspect of the case study.

8.0.2 Synopsis of the Chapter

The chapter commences with a discussion of the methodological issues surrounding the development of aggregate environmental indicators, and the types of approach taken in typical contemporary studies. Section 8.2 presents the method developed in this study, involving the test of covariance, the interpretation of R_j as an aggregate ranking method for TAEs, and an analysis of the sensitivity of the aggregate ranking to different weighting assumptions. The mapping method is described in Section 8.3, and the chapter concludes with an appraisal of the strengths, weaknesses and generality of the method in comparison with the methods of other contemporary studies.

8.1 THE BASIC PROBLEMS IN AGGREGATING AND MAPPING ENVIRONMENTAL INDICATORS

The rational approach to environmental aggregation may be divided into four problem areas:

(i) component attribute selection, (ii) measurement and scaling, (iii) weighting of attributes, and (iv) the aggregation procedure. A selection of three contemporary studies is reviewed with the objective of illustrating the problems, and the ways in which they have been tackled; these may then be compared later in the Chapter with the methods of this research.

8.1.1 A General Appraisal of the Issues

The general problem of aggregating environmental indicators encounters issues which did not present a significant problem in the limited context of area appearance evaluation. The area appearance study was in fact an example of aggregating component aspects of an environmental attribute into a 'primary parameter' (AMMER 1976)[1] for that attribute, and the components possessed many factors in common in respect of both their theoretical properties (for example they were all qualitative, area-based, ordinal indicators) and their conceptual nature (they all shared in the common property of contributing to the overall visual appearance of an area). The more general task of aggregating environmental indicators, often involving indicators which are themselves 'primary parameters', is confronted with methodological problems resulting from the frequent and considerable disparity between the (theoretical and conceptual) properties of the various component indicators. Thus the task of scaling, weighting and aggregating indicators which are measured on totally different scales with scale properties which may range through the full spectrum from ratio to ordinal or even nominal, becomes much more complex. Furthermore the interpretation and understanding of the resulting aggregate environmental indicator is problematical; is it purely an arbitrary collection of different data or does it reflect an internal conceptual identity amongst the components, as in the case of a primary parameter?[2]

A brief summary of the four problem areas (selection, measurement/scaling, weighting, and aggregation) in the rational methodology for achieving the overall (aggregate) value of a composite indicator was given in Chapter 7.1.2, where it was seen to have been used as the (dubious) basis of the 'stimulus/response' approach to area appearance measurement. A full account of the issues in each problem area in the overall environmental context is given by AMMER (1976), MANCHESTER UNIVERSITY (1976) and SOUTH YORKSHIRE COUNTY COUNCIL (1978b), and an extensive application of the analysis to this study was beyond the scope of the research. However it may be noted that since the measurement, and often the selection, of

1.Ammer defines a 'primary parameter' as a single indicator describing the condition of a composite, well-defined environmental attribute, for example 'air pollution' or 'recreational quality'.
2.This issue also affects the ease with which weightings may be established, as seen shortly.

component environmental attributes is usually made prior to any consideration of aggregation (for, as stated in section 8.0.1, aggregation is normally used as a convenient summary or abbreviation of data originally collected for the detailed analysis of individual attributes), it follows that studies of overall environmental aggregation are predominantly concerned with the latter issues of scaling, weighting and aggregation, rather than with definition, selection and measurement issues which have often been decided already on the basis of other criteria. This was indeed true of this case study, and consequently the discussion in this section concentrates upon the issues surrounding scaling, weighting and aggregation.

As discussed in Chapter 7, the aggregation methodology may be applied in two ways, described in the literature under the somewhat misleading headings 'subjective' and 'objective' (e.g. SOUTH YORKSHIRE COUNTY COUNCIL 1978b). In reality the two approaches differ merely in the extent to which subjective judgements are made explicit.

What is termed the 'subjective' approach involves the intuitive 'weighing up' of the values or conditions of the component attributes, their relative importance in determining the condition of the overall concept and the way in which this aggregation takes place. In this instance the need for all components to be expressed on common or 'normalised' scales is obviated, and (as was seen in Chapter 7), interactions between components may be taken into account in the intuitive scaling and weighting process. While the intuitive nature of the process is directly applicable to contexts where a set of purely subjective impressions is evaluated by an observer, its application is more problematical in the overall environmental context where subjective impressions have to be compared and aggregated alongside objective measurements such as air pollution concentrations and noise levels; this particularly applies where there is no clearly evident common conceptual property between components, and for this reason overall environmental aggregation tends to be conducted through what is termed the 'objective' approach (SOUTH YORKSHIRE COUNTY COUNCIL 1978b).

In this approach the judgements necessarily involved in scaling, weighting and aggregation are explicitly quantified, and the method may be conducted through four basic types of mathematical procedure, summarised below.

(a) Arithmetic aggregation; each component attribute is valued on an assumedly ratio scale which must be a common or 'normalised' scale, for instance where measured values are divided by 'standard' values, or where the limits to the range of values are transformed to a scale where the limits are 0 and 100 (e.g. WOOD et al 1974, INHABER 1974; see Section 8.1.2). Weights are determined for each attribute either on theoretical or hypothetical grounds or through the use of the Delphi method (e.g. DALKEY 1969); indicator values are multiplied by their weights and aggregated either through simple or root mean square addition (e.g. INHABER 1974).

(b) Limiting factors; this technique requires a common or 'normalised' scaling system but in some cases the scales need only be ordinal in nature and weightings are not always necessary. The aggregate indicator value is put equal to the limit value (either highest or lowest depending upon the nature of the measurements) of the component measurements. This is used for example in determining an 'agricultural capacity' index (SOUTH YORKSHIRE COUNTY COUNCIL 1978b) where the concept is limited by whatever is the worst condition out of a range of determinants such as climate, soil type, gradient, etc.

(c) Multiple regression; here not only must the component attributes be measureable on interval scales but a further, independent measure of the composite, aggregate condition is also required. The regression performs a statistical analysis on a number of sample data with the objective of determining the most appropriate weighting and aggregation procedure. Through applying mathematical transformations to component variables the mathematical aggregation procedure may be manipulated into a form which best explains the independent measurements; the coefficients derived from the regression are then the best estimates of the weights to be applied to the components. This technique is essentially the same as that used in the sulphur dioxide study (Chapter 6) to ascribe an empirically-derived set of 'emission coefficient' weights to the urban fabric types. Clearly it is highly demanding both in its need for interval scale component measures and, more particularly in the overall environmental context, the need for a single, independent measure of the overall concept on which to base the statistical analysis. SOUTH YORKSHIRE COUNTY COUNCIL (1978b) used the technique in the determination of the primary parameter 'landscape attractiveness', but its usefulness is probably restricted to these types of aggregation where an independent measure of the concept is feasible.

(d) Multivariate analysis techniques; these represent the most sophisticated of the aggregation techniques requiring computer analysis, and are commonly used only when a large number of components (more than ten for example) are present in the analysis; this type of approach is also termed 'numerical taxonomy' (GORDON 1978). Factor analysis or principal components analysis may be used, as in the study by BUCHANAN (1971), to reduce the data variates to a number of 'common factors'; cluster analysis may be used on these or on original data as a method for grouping information into classes (e.g. BUCHANAN 1971, KENDIG 1976, GORDON 1978). Although the above techniques require interval scale data, essentially the same procedure may be applied to ordinally-measured components through the technique of 'unfolding theory' (TRAILL, cited in SOUTH YORKSHIRE COUNTY COUNCIL 1978b), while the simpler ordinal technique of multi-dimensional scaling (KRUSKAL 1964) may also be used.

The choice of an appropriate method will of course depend to some extent on the needs and resources of the study context, but a major constraint upon the application of many of the above quantitative techniques is the invalidity of their application to ordinal-quality data. The criteria for the selection of an appropriate aggregation method are discussed in a more practical context below.

8.1.2 Discussion in Relation to Contemporary Studies

To illustrate the general environmental aggregation problem in a more practical way, it is useful to discuss the issues in relation to contemporary studies that have used aggregation; particular reference is given to three studies which between them cover the range of types of approach, study contexts and component indicators that have been used; the studies were of Canada (INHABER 1974, 1977), the Dortmund area of the Ruhr Valley in West Germany (KARPE and SCHOLZ 1976), and the Greater Manchester conurbation in the UK (WOOD et al 1974).

As stated the selection of the particular component indicators is usually dictated by their availability from national monitoring programmes, local authority studies, etc., but broadly, attempts are made to cover the four basic types of attribute given in Chapter 1.1, viz air, land, water and noise. Table 8.1 compares the component attributes used in the three contemporary studies and includes those used in this research, from which the comparatively limited scope of this research case study is evident. It should be noted that, as stated in Chapter 1.1, the classification of the environment, leading to the definition of the individual component attributes, is dependent to some extent upon the policy context of the study; for example Structure Plan reports of survey will obviously consider the attributes likely to be affected by Structure Plan policies.

Table 8.1 Environmental Indicators Used in Contemporary Studies

Canada (Inhaber 1974)	Ruhr (Karpe & Scholz 1976)	Gtr. Manchester (Wood et al 1974)	West Midlands (Pocock 1979)
Air (several indicators Water (several indicators Land (several indicators) Miscellaneous (Pesticides, Radioactivity)	Air (sulphur dioxide, dust) Noise (Day noise, Night noise) Socio economic factors. (Green space, transport systems, Recreational facilities)	Air (Smoke, sulphur dioxide) Land (Spoil tips, waste land) Water (River, Canal quality) Traffic (Traffic Density)	Air (sulphur dioxide) Land (visual condition only) Noise (L_{10}, L_{90}, L_{eq})

Faced with a wide variety of measurement systems and measurement scales for the component attributes, each study involves a means of what is generally but rather misleadingly termed 'common scaling'. Although the methods for achieving this are varied (as seen below), the principle is essentially to apply a 'scaling transformation function' (AMMER 1976) to each of the available measurement scales, such that for each attribute the data are normalised, and all attribute measures are expressed in terms of the same numerical scale units or scaling base criteria. As mentioned below however, it is misleading to term these 'common scales', since the process of transformation and normalisation does not make the scales <u>commensurate</u>; it is therefore more appropriate to describe the procedure as 'common normalisation'.

In the study by Inhaber the 'common normalisation' method was to divide each measurement by a 'standard value' as a criterion of acceptable conditions but "it was not possible to be consistent with respect to the criteria throughout the entire (attribute set) because of the wide variety of data and the general lack of official standards" (INHABER 1974). Karpe and Scholz set measurement scale limits of '0' for "pollution-free" and '1' for "pollution-saturated" conditions, with a linear scaling transformation function to transpose intermediate values to values between 0 and 1.

Wood et al took a more empirical approach, with the lowest observed measurement value put equal to 0 and the highest equal to 100, and again a linear transformation was used for intermediate values. It should be noted that in each of these methods it is assumed that each component indicator is measurable on a cardinal (i.e. interval or ratio) scale. Furthermore, AVEROUS (1978) has pointed to the fact that transformation to a common or 'normalised' scaling base involves an implicit weighting to the measurement scales in addition to any weighting explicitly included in the process of aggregation. This is because the subsequent treatment of the 'normalised' data is based upon the assumption that the scales are commensurate when in fact this is not necessarily so.

Thus it is evident that while simple and readily applied, these approaches are of questionable validity in overall environmental aggregation, especially since several important environmental variables are only measurable in terms of ordinal data. It will be seen that the aggregation method proposed in this case study requires only ordinal data assumptions and is therefore potentially more theoretically sound.

The 'common normalisation' scaling systems of the three study examples are compared in Table 8.2, which also summarises the weighting and aggregation methods, and compares the studies with the approach proposed in this research and described in the following section 8.2. From the Table it may be seen that Inhaber, and Karpe and Scholz, use explicit numerical weightings for component attributes, derived from the considerations of groups of experts - in Karpe and Scholz's case using the Delphi technique for obtaining a group consensus (e.g. DALKEY 1969, VARIOUS 1975); Wood et al on the other hand use an unweighted (i.e. unitary weighting) method. The same assumption was implicit in the method of this research although it will be shown that the spatial covariance of the attributes reduces the significance of the whole weighting procedure. The more cautious attitude

Table 8.2 Comparison of Aggregation Methods in Contemporary Studies

Study / Stage of Aggregation	Canada (Inhaber 1974)	Ruhr (Karpe & Scholz 1976)	Greater Manchester (Wood et al 1974)	West Midlands (Pocock 1979)
'Common normalisation' system for component indicators	Cardinal (measure/ standard ratio)	Cardinal (0 to 1 for 'worst' to 'best' possible conditions)	Cardinal (0 to 100 for lowest to highest observed conditions)	Ordinal (Ranking of area types)
Weighting System	Numerical, by experts	Numerical, by experts using Delphi	Unity (specified, for all indicators)	Unity (Implicit, method limited to concordant indicators)
Aggregation method	r.m.s. addition	Arithmetic mean	Arithmetic mean	Kendall 'best estimate ranks'
Representational method	Tables	Isoline map	Choropleth map, municipal zones	Choropleth, grid square TAE zones

of Wood et al stems from their general conclusion that in view of the 'speculative and incomplete' nature of current knowledge of the relative and combined effects of different environmental attributes, "there is a preference for simple standardisation and weighting methods since nothing is gained from using the more sophisticated systems" (WOOD et al 1974). In fact this attitude is reflected in all three studies discussed here, and indeed in this research case study method also, and is particularly well evidenced in the use of the simplest, arithmetic, aggregation methods.[1] The more sophisticated of the methods listed in section 8.1.1 have generally been applied only to limited ranges of component attributes having distinct common properties (for example the components of 'landscape attractiveness' and 'residential area quality').

Despite deliberate concessions to the need for caution, it has been seen that the three methodologies maintain the assumption of cardinal-scale attribute measurements and an explicit definition of weights (even Wood's unitary weighting system involved explicitly-assumed weights). The validity of both these assumptions was shown to be questionable in overall environmental aggregation; in contrast it will be seen that the method of this research requires only ordinal data assumptions, and its application to covariant attributes, while limiting the comprehensiveness of the method, means that the significance of the weighting problem is considerably reduced.

8.2 THE TEST OF THE KEY HYPOTHESIS, AND DESCRIPTION OF THE ORDINAL AGGREGATION METHOD

It was stated in the introduction that the key hypothesis in this case

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1. As shown in Table 8.2, simple and r.m.s. addition are used, the distinction between them being that the r.m.s. method gives greater emphasis to extreme values.

study was the assumption of a spatial covariance between the three component attributes. Upon validation of the hypothesis it may be stated that any aggregate indicator composited from the three attributes must be significantly associated with the TAE types. Since such an association has already been shown to exist in the case of each individual component, this means that TAE types may again be used as the basis for a spatial prediction model, in this case involving an 'aggregate environmental indicator'. The TAE prediction model is actually a method for ranking the TAE types with respect to their aggregate environmental condition, with the aggregate environmental indicator ranking being obtained from the Kendall 'sum of ranks' parameter R_j - which is itself the key parameter upon which the test for covariance is performed.

8.2.1 The Test for the Spatial Covariance of the Attributes

The data for testing the hypothesis of spatial covariance were provided by the TAE prediction models of the three attribute case studies. These, (constituting a summary of the Phase 1 surveys and sample predictions from the sulphur dioxide diffusion model), were the only valid sources of data; the alternative of randomly sampling the predicted conditions of TAEs from the mapped data would not result in a statistically independent set of samples because in the cases of ambient noise and area appearance there are in fact only nineteen independent samples - the TAEs from which the prediction models were derived.

The raw data for the test therefore consisted of three sets of environmental data for the set of TAE types: an interval-scale set of ambient noise levels obtained from the Phase 1 field-survey of sample TAEs; a ratio-scale set of sulphur dioxide concentrations predicted for a sample of TAEs using the urban diffusion model, and an ordinal-scale set of area appearance scores obtained from the Phase 1 field survey of sample TAEs. The hypothesis under investigation was that the variations in the conditions of the individual attributes across the different TAE types were associated; in fact, specifically, the test was performed upon the null hypothesis that no covariance or association existed between the three above-defined data sets. The scale properties of the data sets mean that a test compatible with all three attributes must be non-parametric, and for this reason it was necessary to use the Kendall Coefficient of Concordance, w, as the test of covariance, and therefore to reduce the raw data to a common, non-parametric base by converting it to sets of rankings of the TAE types with respect to each of the three attributes. The Coefficient of Concordance may then test the null hypothesis that the three sets of rankings are independent.

The data used in the case study are shown in Table 8.3, which contains both the original TAE prediction model conditions and the corresponding rankings. It will be seen in the study of aggregation (section 8.2.2) that the conversion of the data to an ordinal data base constitutes the non-parametric equivalent of the process of applying 'scaling transformation functions' to (assumedly) cardinal data with the aim of achieving a 'common normalisation' of the scaling system (as discussed in section 8.1.2). The nature of the test for concordance has already been described in Chapter 7.3.2 and the method for calculating w was given by Equation 7.2. For each sample TAE type, j, a Kendall 'sum of ranks' parameter R_j is calculated and the test examines whether the resulting distribution of R_j values is significantly different from what might be expected assuming the attributes to be independent. The distribution of R_j values resulting from the case study data is shown in Table 8.3, and using Equation 7.2 a value of $w = 0.75$ was obtained. The significance of this value was tested through the Chi-squared test using the equivalent Chi-square value of 40.5, derived through the method due to SIEGEL (1956). From Tables, with the appropriate 18 degrees of freedom, Chi-squared is significant at the 1% level for values exceeding 34.8, and at the 0.1% level for values

Table 8.3 Attribute Prediction Model Values and Rankings, and Resulting 'Sum of Ranks' Parameter R_j

TAE Type	Prediction Model Values			Ranking of Prediction Model Values			'Sum of Ranks' R_j
	Ambient Noise L_{eq}, dBA)	Sulphur Dioxide (ug m^{-3})	Area Appearance (Score)	Ambient Noise	Sulphur Dioxide	Area Appearance	
6A	66.2	134	2	2	1	2=	5.5
6B	64.2	109	2	3	6	1	10
4A	61.9	115	2	4	4	2=	10.5
2A	67.7	126	6	1	2=	10	13.5
1B	60.6	114	3	6	5	6	17
1A	59.4	126	4	7	2=	8	17.5
4B	60.4	103	4	8	7	7	22
8B	63.3	79	3	5	14	4	23
0A	55.8	90	5	10	11	9	30
5B	54.9	95	5	12	9	11	32
5A	54.7	97	7	13	8	12	33
8C	53.9	77	3	15	16	5	36
5C	57.1	79	8	9	13	14=	36.5
0B	53.0	91	7	14	10	13	37
7A	56.1	78	8	11	15	17	43
7B	51.8	82	7	16	12	16	44
7C	48.8	73	8	18	18	14.5	50.5
0C	49.6	75	8	17	17	18	52
3C	43.7	54	9	19	19	19	57

exceeding 41.6. Thus the null hypothesis was rejected and it was concluded that there was a 99% probability that the three attribute rankings were not significantly different - in other words, that they were effectively sampled from the same 'parent' population ranking.

The interpretation of this result in the context of aggregation is discussed in more detail in the following section 8.2.2. Here it may be stated that the finding of significant concordance means that the three attributes are significantly spatially covariant, since the test was performed upon data selected on a spatially comprehensive sample frame. This finding makes an important contribution to the theoretical knowledge of the nature of urban environmental conditions, and supplements the work of WOOD et al (1974), who found a spatial covariance to exist between several environmental attributes taken on a pairwise basis. Wood et al used their discovery of covariance in a practical context as a means for predicting the values of indicators for which measured values were not available, using instead the (common scale) values of other indicators with which covariance had been established. This provides an example of the general application of covariance to the definition of 'key indicators', the patterns of which may be used as surrogates for the patterns of other indicators with which they are covariant. The 'key indicator' technique is in effect a method of aggregation, and in this case study the finding of covariance may be taken to show that any aggregate indicator of ambient noise, sulphur dioxide and area appearance, however achieved, must necessarily be associated with TAE type since each component has itself been found to show significant relationship with TAE type. The covariance test may therefore be taken as a test of the TAE hypothesis for any aggregate indicator of the three component attributes of this research.

8.2.3 An Ordinal Aggregation Method and TAE Prediction Model

The key to the ordinal aggregation method proposed in this research is given by the already-stated conclusion of the concordance test - namely, that the TAE rankings derived from the sets of sample data for the three attributes were not statistically significantly different from independent, random samples of a single 'parent population' ranking. In other words the statistical evidence cannot distinguish between the three sample rankings.

Under such circumstances KENDALL (1948, cited in SIEGEL 1956; see also EDWARDS 1964) has argued that in statistical terms there is only one 'true' parent population ranking of the samples, and each attribute measure "is applying essentially the same standard in ranking the objects (here, TAE types) under study" (SIEGEL 1956). In the context of the research this means that there is essentially no difference between the intrinsic standards underlying the measures of the attributers, and in this sense each attribute is seen to have a share in an undefined 'common property', this being the underlying standard that gives rise to concordance amongst the attributes. In the research this common property was interpreted as the 'aggregate environmental condition', although this is strictly just a terminological definition for the conceptual underlying ranking.

Kendall has further argued that the best estimate of the underlying ranking of a set of concordant attributes is given by the ranking of the 'sum of ranks' parameter, R_j. Under the conditions of concordance, where there is no statistical evidence to suggest the attribute rankings are significantly different, each ranking may be treated as an independent, unbiased sample of the underlying concordant ranking, and consequently the 'sum of ranks' parameter is the best available estimate of this underlying ranking. Consequently in the interpretation posed above, the best estimate of the 'aggregate environmental condition' ranking is given by the ranking of R_j.

In making this interpretation of the consequences of concordance amongst the attributes, three points should be noted. Firstly, it is seen that since all three attribute rankings are equally valid as estimates of the underlying ranking, this means that the 'best estimate' ranking is based on an assumed equal weighting of the attributes; secondly its validity as a method of determining an overall aggregate ranking of attributes is maintained only in circumstances where concordance has been demonstrated. Moreover it should be noted that what is achieved is not in any operational sense a measure of aggregate conditions; rather the method is simply a procedure for achieving an overall ranking of three sets of data, and by extension an overall ranking of the nineteen types of area of which the study area is composed.

Table 8.4 shows the R_j values and the equivalent rankings of the TAE types in terms of their aggregate environmental condition as provided by this research method. Since these results are rankings, rather than ordinal scores such as those attained in the area appearance study, the resulting prediction model is of a different (lower) order than those achieved in any of the other case studies; nevertheless to aid comparability the rankings are presented in the form of a TAE prediction model in Table 8.5.

The predicted rankings have been seen to result from an assumption of equal attribute weightings; a simple test of the significance of this weighting assumption may be derived from the individual attribute rankings which were given in Table 8.3. Clearly these rankings are equivalent to those that would be achieved from aggregations where the weightings for each attribute in turn tend to dominate, i.e. become infinitely high. Thus for any given TAE type the amount of difference between its three individual attribute rankings indicates how sensitive its aggregate ranking is to alternative weightings of the attributes; if differences are small then the

Table 8.4 Ranking of R_j Values, and 'Weighting Sensitivity Parameter' Values, D

TAE Types	R_j Values	Ranking of R_j	'Weighting Sensitivity Parameter', D
6A	5.5	1	1.5
6B	10	2	5
4A	10.5	3	1.5
2A	13.5	4	9
1B	17	5	1
1A	17.5	6	5.5
4B	22	7	1
8B	23	8	10
0A	30	9	2
5B	32	10	3
5A	33	11	5
8C	36	12	11
5C	36.5	13	5.5
0B	37	14	4
7A	43	15	6
7B	44	16	4
7C	50.5	17	3.5
0C	52	18	1
3C	57	19	0

Table 8.5 TAE Prediction Model for Aggregate Environmental Ranking

Land Use	ROAD NETWORK DENSITY		
	A. Dense	B. Medium	C. Sparse
0. Residential	9	14	18
1. Industrial	6	5	*
2. Commercial	4	*	*
3. Open Space	*	*	19
4. Res/Ind	3	7	*
5. Res/Comm	11	10	13
6. Ind/Comm	1	2	*
7. Res/O.S.	15	16	17
8. Ind/O.S.	*	8	12

*: Insignificant Proportion (less than 0.5%) of total WMMC Area.

aggregate ranking will be relatively insensitive to weighting changes, but if differences are large then the aggregate ranking will be more critically dependent upon the choice of relative attribute weightings. This simple kind of test was effected through the definition of a 'weighting sensitivity parameter', D, where values of D were given by the numerical difference between the highest and lowest individual attribute rankings for any given TAE type. Thus D-values were derived from the data in Table 8.3 and are shown against the aggregate rankings in Table 8.4. It is seen that there are roughly three groups of D-values; (i) there are nine TAE types for which D-values are equal to or less than 3 - in other words even across the maximum possible range of alternative weightings their aggregate ranking does not change by more than three ranks; (ii) there are seven TAE types whose D-values lie between 4 and 7 and for which the choice of weightings has a more significant effect upon their aggregate ranking; and (iii) there is a small group consisting of three TAE types (commercial centres and areas where industry is mixed with open space) with D-values exceeding 10 and for which therefore the choice of weightings is highly significant in the determination of the aggregate ranking.

A more pertinent test of the sensitivity of aggregate rankings would have been achieved if the results appropriate to a range of realistic alternative weightings had been compared, but this extra effort was not considered necessary since the 'extreme case' approach using D-values was adequate for the purposes of this research. In the final analysis the objective of the research was to use the TAE prediction model as a mapping method involving five groups of TAEs, associated with five categories of aggregate environmental condition. As seen in the earlier case studies, the accuracy required of the TAE prediction model is that which is necessary to achieve 'significant gaps' between TAE types equal to or less than the metric scale 'intervals' covered by the five groups. In this case, the grouping of nineteen ranks into five groups means that in general the group 'interval' is about four ranks, and therefore the accuracy of the TAE prediction model should be such that there is no significant chance that the predicted ranking of a TAE type is in error by more than four ranks. Considering the D-values shown in Table 8.3 (the D-value is the nearest equivalent to an 'error of estimate' for this kind of model), and bearing in mind the fact that the D-value is based on unrealistic 'extreme case' weightings, it was concluded that only the TAE types in (iii) above were sufficiently sensitive to stand a significant chance of 'changing group' under realistic weighting alternatives. For the remainder of the TAE types, it was assumed that the concordance between the attributes was sufficient to remove the chance of a 'group change' occurring under realistic weighting alternatives.

The identification of a very few TAE types where a high sensitivity was detected shows that in their case a closer attention to the choice of appropriate attribute weightings should be made; however the general sensitivity test served a useful purpose in this respect by reducing the number of area types for which the weighting issue need be considered, for not only is the practical effort of assessing the appropriate weightings of the TAE types correspondingly reduced; the methodological problems which are encountered if it is decided that different weightings should be applied in different types of area are also reduced. For example the case study has shown that the TAE types with the greatest sensitivity to weighting do not include residential areas - therefore weighting considerations particular to residential areas may be neglected. In summary the sensitivity test suggests that a selective approach to the weighting issue might be taken, such that many of the complex problems involving matters like the interaction between the attributes and with the type of area - problems which have lead workers such as Wood to opt for simple unitary weightings - may become more tractable by reducing the number of circumstances where weighting has to be considered. However the actual conduct of a specific weighting analysis was beyond the scope of the case study, and the study proceeded upon the basis of the already-presented aggregation with assumed equal weightings.

The limitation of the aggregation method to concordant indicators does of course constrain its generality. However there is both empirical and theoretical evidence to suggest that spatial covariance of environmental indicators is quite common, particularly in urban areas. WOOD et al (1974) have shown that covariance exists between several physical environmental indicators[1] in the Greater Manchester conurbation, and both

1. For instance, positive correlation (at greater than 95% confidence) was found between river pollution and smoke, sulphur dioxide and traffic pollution, and between smoke and sulphur dioxide, while negative correlation was found between canal pollution and traffic and river pollution.

Wood et al and KARPE and SCHOLZ (1976) have shown that environmental indicators are covariant with socioeconomic indicators such as car ownership, employment type, etc. Theoretically too a widespread spatial covariance is to be expected from the principal spatial hypothesis that environmental conditions are strongly determined by the "degree and type of land use activity" (WOOD et al 1974) in an area, since for example a large number of negative environmental factors are associated with pollution-generating land uses such as industry, and intense land use activities. Thus although the validity of the method is limited to concordant indicators and only three attribute indicators have been tested in the case study, there is evidence to suggest that concordance may be quite a common phenomenon and therefore that a single aggregation might encompass a wide range of indicators. Moreover a truly comprehensive range of environmental indicators[1] might be clustered into just a few (e.g. two or three) groups of mutually concordant indicators for each of which a single aggregation could then be obtained, thus aggregating the comprehensive range into a very small number of 'leading indicators' rather than a single overall environmental indicator.

8.3 APPLICATION OF THE ORDINAL AGGREGATION AS A MAPPING METHOD

Although the TAE prediction model in this study only predicts rankings for the TAEs (in contrast to the scores and measurements of the previous case studies), it may still be applied as a mapping method, so meeting the third objective of the TAE methodology. The grouping and mapping procedure followed the same techniques as those adopted in the area appearance study.

8.3.1 Grouping the TAEs, and the Nature of the Resulting Categories

It has been seen that the most precise 'measure' of aggregate

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1. But note that the method described here would still limit such a 'comprehensive' range to those indicators that may be treated by the 'TAE' approach (see Chapter 4.1).

environmental conditions is the Kendall 'sum of ranks' parameter R_j. This was therefore used as the basis for the grouping method just as it was in the area appearance study, and the values of R_j and the resulting groups are shown in Table 8.6. As before, the R_j scale has strictly ordinal properties, but large numerical 'gaps' between successive R_j values were interpreted as indicating a particularly high confidence in distinguishing a rank differentiation of the values in preference to a tie, and thus large R_j intervals were used to guide the demarcation of groups, in addition to the consideration of urban fabric consistency in the manner of previous studies.

The groupings defined by Table 8.6 were used to achieve a predicted map display of aggregate environmental conditions across the WMMC through the familiar TAE methodology. The resulting maps are shown in Figs. 8.1 and 8.2, describing all five categories, and 'stress' (group 2) and 'high stress' (group 1) categories respectively.

8.3.2 <u>Discussion of the Resulting Maps</u>

Examining the 'grouped' version of the TAE prediction model given in Table 8.6, it is seen that group 1 contains the old, major industrial centres, and also the major commercial centres. Although R_j values would tend to imply that types 2A (commercial, dense network) and 4A (residential/industrial mix, dense network) should be in group 2, they were allocated to group 1 because they are more clearly associated with the 'mixed commercial and industrial centre' characteristics of types 6A and 6B than the otherwise solidly industrial group 2. From the maps it is evident that these 'stress' and 'high stress' categories tend to be located in and to the north east of Birmingham's inner city, and to the west of this, in and around the old industrial centres in the Northern part of the Black Country (e.g. Wolverhampton, Walsall, Bilston and West Bromwich) and also in and to the north of Coventry. Group 3 contains

Table 8.6 Grouping of TAEs: Predicted R_j Values, Ranks, and Description of Each Group

Group	TAE Type	R_j Value, and Rank ( )	Ranges of Ranks in each group	% of WMMC area in each group
1	6A Comm/Ind/Dense 6B Comm/Ind/Medium 4A Res/Ind/Dense 2A Commercial/Dense	5.5 (1) 10 (2) 10.5 (3) 13.5 (4)	1-4	6.5
2	1B Industrial/Medium 1A Industrial/Dense 4B Res/Ind/Medium 8B Ind/O.S./Medium	17 (5) 17.5 (6) 22 (7) 23 (8)	5-8	13.7
3	0A Residential/Dense 5B Res/Comm/Medium 5A Res/Comm/Dense	30 (9) 32 (10) 33 (11)	9-11	10.2
4	8C Ind/O.S./Sparse 5C Res/Comm/Sparse 0B Residential/Medium 7A Res/O.S./Dense 7B Res/O.S./Medium	36 (12) 36.5 (13) 37 (14) 43 (15) 44 (16)	12-16	35.5
5	7C Res/O.S./Sparse 0C Residential/Sparse 3C Open Space/Sparse	50.5 (17) 52 (18) 57 (19)	17-19	34.1

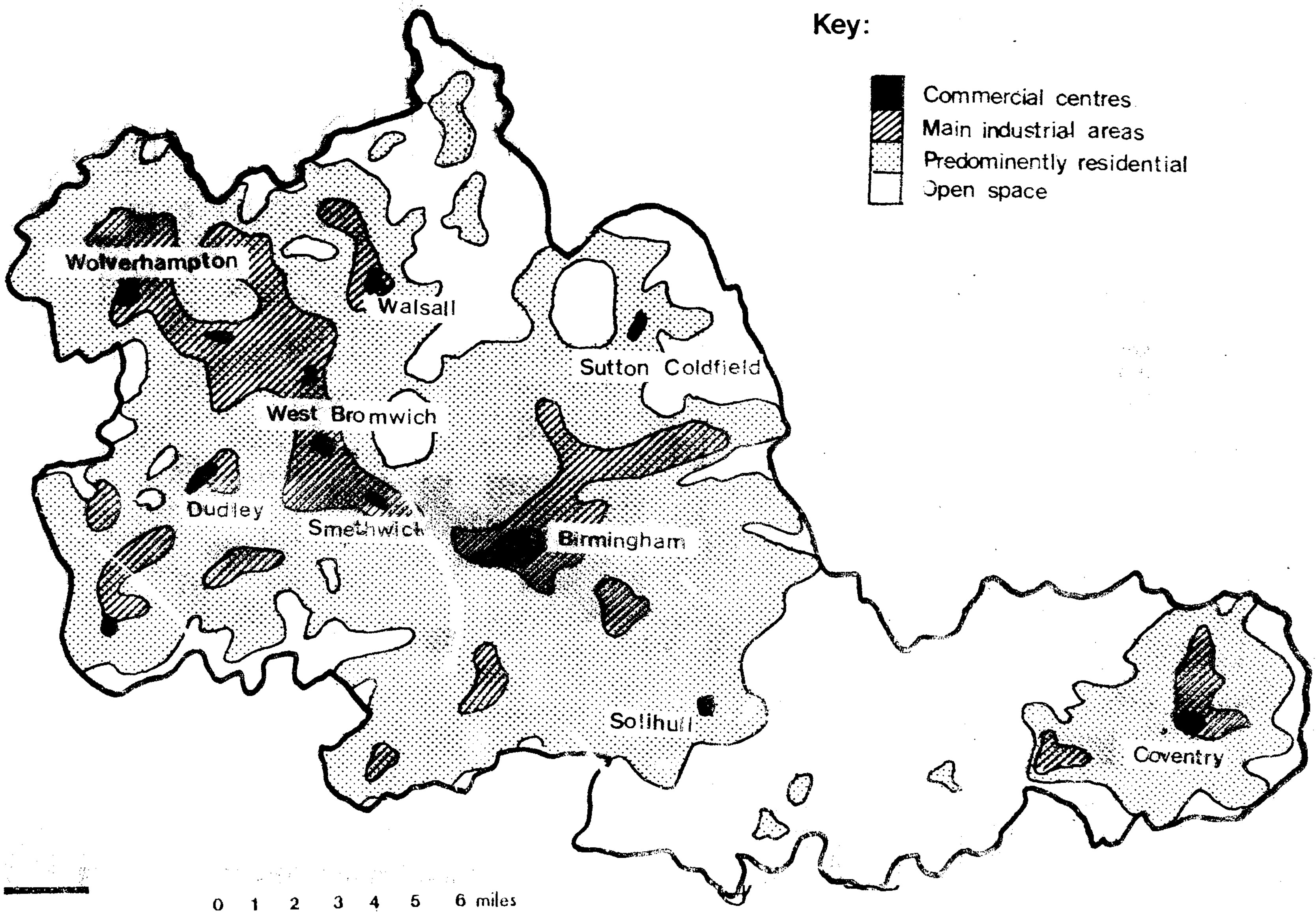

Fig 8.1 Man showing predicted aggregate environmental conditions in the WMMC

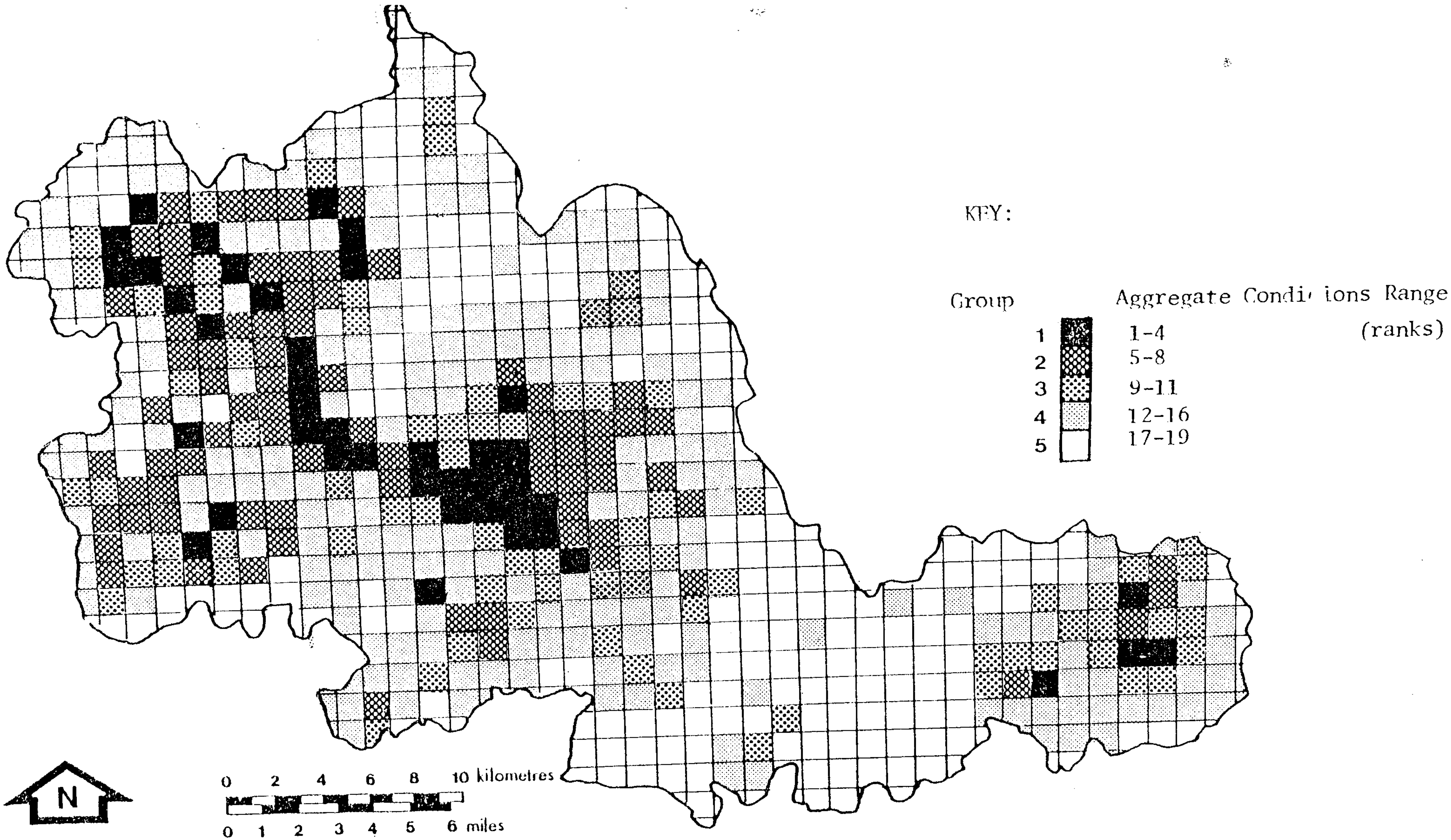

Fig 8.1 Map showing predicted aggregate environmental conditions in the WMMC

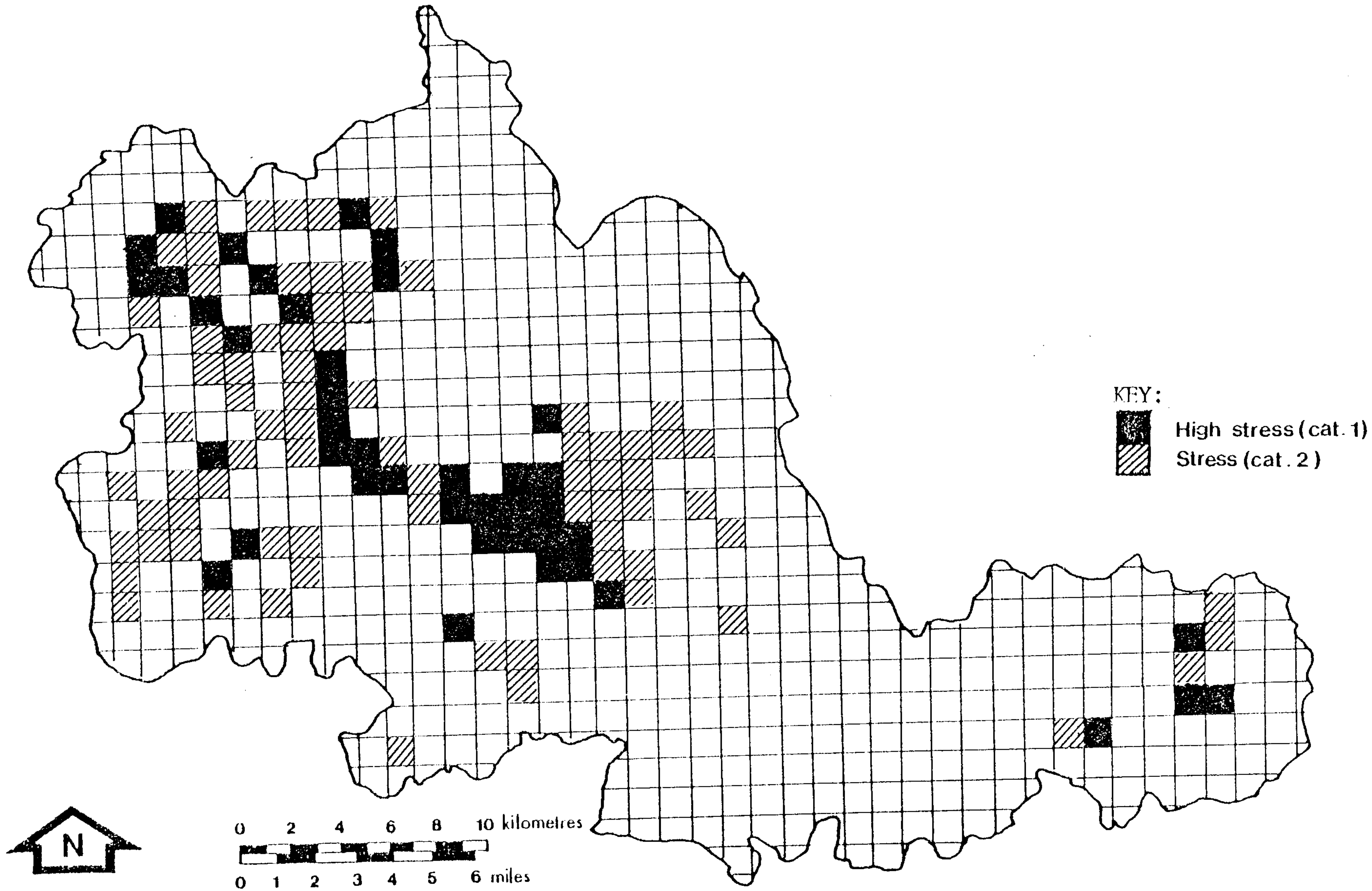

Fig. 8.2 Map showing the location of 'stress' and 'high stress' aggregate environmental conditions.

the main suburban commercial areas and the residential areas where the road network is dense. These areas are common in the central parts of the conurbation and around the south and east of Birmingham. Group 4 is clearly distinguishable on the R_j scale; while predominantly lower density residential it also contains the shopping and industrial areas that are found in sparse networks. The group is common to the south and west of Birmingham and in the southern and northern limits of the Black Country. Group 5 consists mainly of rural areas and residential areas mixed with open space and with sparse road networks. Thus the group is found in the 'Green Belt' and district of Solihull, and to the north west of Birmingham and Sutton.

When comparing the maps of 'aggregate environmental conditions' with the individual attribute maps of the other three case studies - and indeed when comparing the attribute maps amongst themselves - a notable similarity of pattern is evident. This is a direct concomitant of the concordance that exists between the attributes, and its effects are further illustrated by comparing the TAE type compositions of the respective groupings, as given in Table 8.7. It may be seen that many TAE types are allocated the same group number in each of the four studies, and in no case is there a disparity exceeding two group numbers. Furthermore, the 'Weighting Sensitivity Parameter' values, D, show that even across the maximum range of possible weightings there are few TAEs whose aggregate ranks change sufficiently to allocate them to a different group to that resulting from an 'equal weighting' assumption. In comparing the indicator values it has been mentioned (Chapter 6.5.1) that it is fortuitous for display purposes to have equal land area proportions in the equivalent categories of each indicator, and Table 8.8 shows that such conditions do indeed obtain over the four case study groupings; again this is in great part due to the concordance of the attributes, and it enhances the visual impression of similarity between the maps.

Table 8.7 Comparison of the Group Categories Allocated to Each TAE Type in the Four Case Studies

TAE Type	Group Categories			
	Ambient Noise	Sulphur Dioxide	Area Appearance	Aggregate Condition
6A	1	1	1	1
6B	2	2	1	1
4A	2	2	1	1
2A	1	1	3	1
1B	2	2	2	2
1A	2	1	2	2
4B	2	2	2	2
8B	2	4	2	2
0A	3	3	3	3
5B	3	3	3	3
5A	3	3	3	3
8C	4	4	2	4
5C	3	4	4	4
08	4	3	4	4
7A	3	4	5	4
7B	4	4	4	4
7C	5	5	4	5
0C	4	4	5	5
3C	5	5	5	5

Table 8.8 Comparison of the Percentages of Total WMMC Area Allocated to Each Group in the Four Case Studies

Group	Ambient Noise	Sulphur Dioxide	Area Appearance	Aggregate Conditions
1	2.0	3.5	5.4	6.5
2	16.1	16.1	16.0	13.7
3	16.5	18.1	13.3	10.2
4	31.1	30.7	42.1	35.5
5	34.3	31.6	23.2	34.1

8.4 COMPARISONS AND CONCLUSIONS

Because the aggregation method is limited to ranking the TAE types rather than achieving measures or scores for them, it is not possible to make a meaningful comparison of the case study results with the results of other studies. Consequently this final section is restricted to giving conclusions in respect of the method itself, and making an appraisal of how it compares with other methods.

8.4.1 Summary, Comparison and Conclusions in Relation to the Aggregation and TAE Mapping Methodologies

The aggregation method and the application of the results to the TAE methodology are discussed in turn. This order reflects the distinction between this case study and the preceding three. The individual attribute studies were primarily concerned with testing the TAE methodology, with the measurement of the attributes constituting a secondary objective merely enabling an empirical testing of the methodology; by contrast the aggregation study described in this Chapter has been principally concerned with discussing methods for aggregating indicators expressed by the TAE technique, while the empirical test of the application of the aggregate indicator to the TAE methodology itself is of secondary importance since in that field no new methodological or data collection issues were introduced.

(a) The Ordinal Aggregation Method

(i) The research case study presents and discusses an ordinal aggregation method for spatially covariant indicators which may be expressed using the TAE methodology, and applies the method to the three attribute indicators already examined in the research.

(ii) The validity of the method holds only for spatially covariant (i.e. concordant) sets of indicators. In the case study concordance was tested through the Kendall Coefficient of Concordance, applied to data consisting of the spatially comprehensive and independent set of samples given by the TAE prediction models of the three preceding attribute studies. The existence of concordance implies that, conceptually, an underlying ranking of TAE types exists, constituting a 'parent population' ranking of which the three individual attribute rankings are effectively samples. The conceptual underlying ranking was taken as the aggregate environmental ranking of the TAE types.

(iii) Statistically the best available estimate of the underlying ranking of a concordant set of data is given by the ranking of the 'sum of ranks' parameter, R_j. Thus R_j values were calculated and ranked to give the ordinal 'aggregate environmental ranking' of the TAE types.

(iv) This method assumes equal weightings for each of the component attributes. A simple sensitivity test found however that concordance was sufficiently prevalent amongst the TAE types for their overall rankings to be effectively independent of individual attribute weightings. A small number of TAE types with a stronger sensitivity to weighting (commercial centres and areas where industry is mixed with open space) were isolated, and it was suggested that should any detailed attempt be made to determine appropriate attribute weightings, this could be restricted to a consideration of these areas alone, thereby considerably reducing the methodological problems involved.

(v) Because the method makes only ordinal assumptions about the data, it obviates the stringent need for cardinal indicator measures and 'common normalisation' scaling systems that constrains the more common mathematical aggregation methods, and limits their applicability if validity is to be maintained. It is therefore potentially a more comprehensive aggregation method, especially in view of the number of environmental attributes that are only measurable in terms of ordinal data. Furthermore the utilisation of concordance considerably reduces the significance of the weighting problem, which is the second major methodological constraint upon the alternative contemporary aggregation techniques.

(vi) The major constraints on the comprehensiveness and generality of the aggregation method are its restriction to attributes susceptible to the TAE methodology, and to attributes exhibiting spatial covariance. However it has been seen (section 8.2.3) that there is evidence from contemporary research (e.g. WOOD et al 1974) to suggest that, especially within urban areas, a wide range of environmental indicators may exhibit covariance and it is possible that a comprehensive range of environmental attributes might be reduced to two or three 'orthogonal' sets of mutually concordant indicators, each of which could be aggregated by the method of this research and mapped as a 'primary (factor) parameter'. Further research is however required to substantiate these suggestions. The major constraints in the ordinal nature of the aggregation are that the results cannot be compared between study areas (unless the data are pooled) or within a single study area over a period of time to detect trends (again unless data are pooled); in other words the usefulness and generality of the method are impaired as against cardinal methods because of the lack of scores or measures defined by external 'absolute' criteria.

(b) Classification of areas: the TAE hypothesis

(i) The existence of significant concordance between component attributes means that any aggregation of the attributes, however achieved, must necessarily result in indicator values which are significantly associated with TAE type, since each attribute has been individually significantly associated with TAE type. The test for concordance is therefore effectively a test of the basic TAE hypothesis.

(ii) The ability to classify the study area into a limited number of area types is a vital and necessary prerequisite for the ordinal aggregation procedure, because its essential ranking process relies on the existence of distinct, discrete units of area the aggregate conditions of which may be ranked.[1] In other words the ordinal aggregation method is only operational on area-based data. In this respect the TAE methodology is extremely useful since not only does it provide a simple method for classifying the study area into areal units, but the classification is made in terms of parameters that are of interest in planning contexts, and the standard TAE unit of area provides a common area base, which is a necessary pre-requisite for the individual component attributes of the aggregation.

(c) The TAE prediction model

(i) The model predicts the ordinal rank of each TAE type with respect to its aggregate environmental condition as defined by the method already summarised. The ranked nature of the predicted data is lower in informational terms than the scores and cardinal measures achieved in the individual attribute models, but the theoretical validity of the method is sound. While a cardinal model would allow a more generalised method, there is no theoretically valid means for achieving this where one or more of the components (e.g. area appearance) is only measurable in terms of ordinal data.

(ii) It was not feasible to test the accuracy of the model predictions except in the analysis of the sensitivity of the predicted ranking to alternative weighting assumptions, through which it was seen that concordance results in a considerable robustness of the aggregate rankings.

(iii) Prediction models expressed directly in terms of aggregate environmental conditions are uncommon in contemporary studies, because

1.Obviously, point-based data cannot be ranked in a spatially comprehensive study because a study area contains an infinite number of points.

the normal procedure for assessing aggregate conditions is to obtain spatially comprehensive data for the individual component attributes and then to aggregate the data item by item. This for example was the approach taken by SOUTH YORKSHIRE COUNTY COUNCIL (1978a,b), WOOD et al (1974), INHABER (1974), and KARPE and SCHOLZ (1976). In fact prediction models for aggregate (composite) indicators have generally been used only for sectoral or individual media studies - such as the 'landscape attractiveness' and 'agricultural potential' methods described by MANCHESTER UNIVERSITY (1976) and SOUTH YORKSHIRE COUNTY COUNCIL (1978b). Thus there are no models in the literature with which the TAE prediction models may be usefully compared; a further reason for this is the ranked nature of the predicted data, for in such circumstances comparison would only be meaningful if the models were expressed in terms of identical area types.

(d) The TAE mapping method

(i) The method involved the familiar procedure, with the grouping being achieved through an identical method to that used in the area appearance study.

(ii) The choropleth technique is the only valid mapping method for ordinal data, and the TAE methodology represents a very useful means for deriving the units of area to be ranked, grouped and mapped; particularly useful is the ability to compare the aggregate pattern with the patterns of individual attribute indicators over a common spatial base.

(iii) From point (iii) under the 'TAE prediction model' heading it may be seen that contemporary studies of aggregate environmental conditions seldom use predictive mapping methods directly. The normal procedure (e.g. WOOD et al 1974, SOUTH YORKSHIRE COUNTY COUNCIL 1978b) is to achieve spatially comprehensive data describing the component attributes and then aggregate the data by the equivalent of the 'measurement-based' approach to mapping, i.e. by performing aggregation at the spatially comprehensive level. The advantage of the method described in this case study derives from the general character of the TAE methodology - aggregation is performed on only a small sample of data, and comprehensive spatial coverage is achieved with the aid of spatially comprehensive urban fabric data. This considerably improves the computational and operational simplicity of the spatially comprehensive mapping of aggregate conditions. Moreover the results are readily applicable and relevant to general planning contexts since the predictions of aggregate environmental conditions are explicitly related to urban fabric types.

The following Chapter 9 involves an extension of this general appraisal of the TAE methodology. The predicted aggregate environmental conditions are presented in Appendix D in the context of a general summary of the case study results combined with other descriptive details of the TAE types.

CHAPTER 9

CONCLUDING APPRAISAL OF THE RESEARCH

9.0 INTRODUCTION

The research problem addressed in this thesis has been defined as 'the development of a methodology for mapping ambient environmental conditions in urban area'. In this final chapter of the thesis it is necessary to conduct the concluding appraisal in two parts, considering firstly the research project itself, and secondly the TAE methodology which is the fundamental output of the research. This distinction reflects the differences between the various sets of criteria and issues that were laid out in the first three chapters; these criteria and issues are consolidated and summarised in the respective parts of this Chapter as criteria against which to make the appraisals.

9.1 SUMMARY OF THE RESEARCH

The overall task of the research was to respond to the research problem as defined above. The set of aims and objectives through which this response has been achieved was described and presented in matrix form in Chapter 1.4, and the matrix of aims and objectives is repeated here in Table 9.1. Through the development of a conceptual framework approach to the research problem (one of the broad aims of the research), as described in Chapter 2, a set of theoretical and operational demands and constraints was devised which provided the framework for a properly comprehensive response to the research problem. The demands and constraints were tabulated and the Table is repeated in Table 9.2. As discussed in Chapter 2.3 this framework shows that the aims and objectives of this research do not allow for all the key issues surrounding the research problem to be addressed through empirical investigation. This was made inevitable because of both the limited resources and time available, and also the fact that not all the issues are empirically testable. This section summarises the results and conclusions achieved

Table 9.1 Framework For Classifying The Aims And Objectives Of The Research

Dichotomy By Method / Dichotomy By Function	Methodological Aims/Objectives (Concerned with the development of a method for environmental mapping)	Substantive Aims/Objectives (Establishing theoretical knowledge and causal factors relating to environmental conditions, and the broader significance for environmental policy)
Broad Aims (Qualitative, discursive method involving theoretical analysis and review)	(a) Develop a conceptual framework for environmental measurement and prediction. (b) Investigate the theory of spatial representation with respect to operational and theoretical issues. (c) Extent current mapping methodologies through the area-based spatial prediction model.	(a) Review the applications of environmental mapping to operational policy contexts. (b) Establish urban fabric parameters as the key determinants of spatial environmental pattern.
Specific Objectives (Quantitative empirical investigation of specific hypotheses through case study data)	(a) Test methods for classifying areas using urban fabric types, expressing the results in prediction models to be used for mapping. (b) Address the problem of defining and measuring environmental indicators for use in mapping. (c) Address the problem of optimal zone size for the area-based model.	(a) Test the hypothesised relationships between urban fabric categories and ambient noise, sulphur dioxide air pollution and area appearance. (b) Test the spatial covariance of ambient noise, sulphur dioxide and area appearance. (c) Address the problem of achieving an indicator of aggregate environmental conditions.

Table 9.2 Theoretical and Operational Demands and Constraints Affecting Research in the Measurement and Prediction of Environmental Conditions

Type of Demand/ Constraint	Description
Operational Demands (demands for relevance and timeliness)	(i) Definition and measurement through indicators appropriate to policy context and reflecting issues of concern. (ii) Data suitable to different stages in the planning process. (iii) Data suitable for different procedural techniques, evaluation, decision analysis, sensitivity analysis, criteria of choice.
Operational Constraints (constraints of operational feasibility and suitability)	(i) Agency type. (ii) Resources of agency. (iii) Powers of agency. (iv) Political acceptability.
Theoretical Demands (demands for validity	(i) Need for operational definition. (ii) Need for data in suitable form for modelling, analysis and display (e.g. maps). (iii) Need for causality to be established.
Theoretical Constraints (constraints of reliability and availability)	(i) Sampling techniques (spatial and temporal). (ii) Errors and uncertainty in definition, measurement, prediction and forecasting; intrinsically probabilistic situations. (iii) Data level (e.g. scale properties) obtained.

in relation to the aims and objectives of the research, and discusses the limitations in the research that result from the fact that it was not practicable to make a comprehensive response to the 'conceptual framework' of issues.

9.1.1 Results and Conclusions in Relation to the Aims and Objectives

The sequential form of the listing of results and conclusions presented here does not follow identically that of the aims and objectives listed in Table 9.1 because, as stated in Chapter 1.5, there are considerable linkages between these items which mean that it is more efficient to conduct the summary by itemising the key results and conclusions of the research, relating each in turn to the various relevant aims and objectives. Although the empirical investigation of the specific objectives dominated the research, it is more logical to begin with the broad, qualitative areas of the research because these 'lead into' the specific objectives.

(i) A conceptual framework for research in the measurement and prediction of environmental conditions was developed, and the results are described in Chapter 2. A conceptual diagram was devised in which it was seen that the key factors having a bearing upon this type of research may be structured into operational and theoretical demands and constraints. A summary of these was given in Table 9.1. The conceptual framework indicates that the research described in this thesis involves a deeper investigation of the theoretical issues than of the operational issues, the main reason for this being the lack of a range of specific operational case study contexts (see Section 9.1.2). The conceptual framework also provided a means of establishing an appropriate and relevant basis of knowledge upon which the TAE methodology could be developed, and gave the basic underlying operational/theoretical criteria which were used to

1. For example, the broad aim of 'extending current mapping methodologies through the area-based spatial prediction model' subsumes almost all the specific objectives.

assess much of the theoretical and empirical investigation that was involved in the development of the TAE methodology - for example the theory of the mapping method described in Chapter 3.

(ii) The conceptual framework was also useful in the derivation of a systematic and practical list of potential operational policy contexts in which the mapping methodology might be applied ('substantive' aim (a)). Functionally there are seen to be two dimensions of applicability in planning contexts, one linked to theoretical analysis and causal modelling ('analytical' techniques), the other to decision-making, through such procedures as evaluation, decision analysis, sensitivity analysis, decision criteria, etc. ('procedural' techniques). This system was described in Chapter 2. A list of possible policy context applications was given in the conclusion of Chapter 1.1.

(iii) A theoretical investigation of spatial representation was undertaken in Chapter 3, as a means of developing a theoretical approach to the problem of environmental mapping ('methodological' aim (b)). The TAE mapping methodology was seen to evolve out of the synthesis of a range of theoretical and operational considerations. Chapter 3.2 concludes with a set of predominantly analytical criteria which point to the need for a 'natural zone' area-based spatial prediction method. When operational factors are considered in greater detail (Chapter 3.4) it is seen that a grid-square-based method is more useful, chiefly because it satisfies the operational criteria of simplicity, versatility and comparability.

(iv) A hypothetical method of 'area-based spatial prediction model' mapping was developed using an urban fabric classification as the 'predictor' parameter, expressed through the key concept of the TAE. The theoretical basis of the hypothetical method was first promalgated in general terms through the concept of the 'natural zone' TAE discussed in Chapter 3.3.

A more detailed investigation of causal factors and contemporary research, described in Chapter 4, led to the fundamental hypothesis that the spatial variation in environmental conditions is associated with spatial variation in the "degree and type of land use activity" (WOOD et al 1974). The hypothesis was specified through the definition of a set of urban fabric categories (TAE types) resulting from a two-dimensional classification of the urban fabric involving land use types and categories of road network density. At the hypothetical level this meets 'substantive' aim(b) and contributes to methodological aim (c).

(v) The hypothetical method summarised above was tested empirically in four case studies using the WMMC as a case study area. For each case study attribute the empirical procedure was threefold; (A) to test the 'TAE hypothesis' that the environmental conditions of TAE zones were statistically significantly associated with the TAE type of the zones; (B) to calibrate the 'TAE prediction model' by associating each TAE type with a 'typical' area-mean or median environmental condition; and (C) to apply the TAE prediction model as a mapping method, by firstly 'grouping' the TAE types to give five categories of environmental conditions, and then applying this 'grouped' TAE prediction model to an urban fabric base map expressed in terms of TAEs. This empirical method tests the 'methodological' and 'substantive' objectives (a), requires 'methodological' objectives (b) and (c) to be addressed, and makes an empirical validation of 'substantive' aim (b) and 'methodological' aim (c).

(vi) For each case study attribute the TAE hypothesis was found to be validated at above the 99% confidence level. The principle of the test was in each case the classical 'analysis of variance'. The range of attributes selected ensured that a comprehensive range of the methodological problems likely to be encountered in testing the hypothesis were covered; parametric and non-parametric tests were conducted, using ordinal, interval and ratio data, of point-and area- based measurement characteristics, obtained from primary (field survey) and secondary sources. In each case no insurmountable methodological difficulties were encountered.

(vii) In each case the TAE prediction model was calibrated, the resulting models being presented in TAE matrix form in the relevant case study chapters. The overall accuracy of the models is assessed empirically by comparing observed and predicted conditions. In all cases the models were found to be accurate enough to meet the criterion for their application in the mapping method; this criterion was defined to be the requirement that the statistically significant difference ('gaps') between TAE type conditions should be no greater than the group intervals used in the mapping exercise.

(viii) In the case study of aggregate environmental conditions a statistical (non-parametric) test of the concordance between the three individual attribute predictions models was made. A statistically significant concordance was found to exist at the 99% confidence level; because the TAE types comprise a spatially comprehensive 'sample frame' for the study area, it may be inferred that the three environmental attributes are significantly spatially covariant. This responds to substantive objective (b). It was also seen in Chapter 8 that spatial covariance amongst attributes may be used as the statistical basis for an ordinal approach to aggregating environmental conditions (substantive objective (c)). A TAE prediction model of ranked aggregate environmental conditions was achieved, and mapped in the same was as the individual attribute indicators.

(ix) The errors in the predicted environmental maps have two possible causes; firstly, errors (cartographical) in the urban fabric TAE base map, secondly errors in the prediction models due to mis-specification, approximations, unexplained variance, etc. (see Chapter 2.1 for an exhaustive list). The errors of estimate presented in the case study chapters derive empirically from the comparison of observed to predicted conditions, and so both of these sources are subsumed in the magnitude of the errors quoted and their relative importance cannot be assessed by the tests used in this research. This means that without further research it is not possible to assess the extent to which the accuracy of the predictions could be improved by more precise urban fabric data and the extent to which inaccuracy is intrinsic to the methodology. Nevertheless the accuracy obtained was adequate for the purposes of the research, as already stated above (part (vii)).

(x) In the course of the case study tests of the TAE methodology, several other theoretical advances were made. Chief amongst these were, (A) the development of an empirical model for predicting the effects of windspeed on ambient noise levels;(B)the empirical calibration of sulphur dioxide 'emission coefficients' for a range of land use activity types, so that an existing urban diffusion model could be adapted to take an 'emissions inventory' consisting of urban fabric data; (C) the development of an operational method for measuring area appearance based on certain visual characteristics of the physical fabric.

Further conclusions specifically relating to the TAE methodology itself are presented in section 9.2, together with recommendations for future research.

9.1.2 Issues Not Fully Covered In The Research

The conceptual framework detailed in Chapter 2 and summarised in Table 9.2 showed that the aims and objectives of the research were strongly biased towards the theoretical side of the overall range of issues influencing the research problem. This resulted from the fact that while it was within the practicalities of the research to conduct a case study approach focussing upon the general methodological problems concerning environmental measurement and prediction, an analysis of the issues surrounding the operational context of the research problem (local government planning) necessarily concerned outside agencies, information and activities which were beyond the command of the research - and in any case presented a problem the analytical scale of which was beyond the resources and time available to the research, due to the vast data collection and analysis exercise that would be incurred. The limitation of these issues to a broad discussion does however constrain the extent to which the research may be considered to have made a fully comprehensive response, particularly with regard to the operational usefulness and application of the TAE methodology.

Other important methodological issues were not fully investigated. The issue of the choice of optimum zone size and configuration (e.g. the choice between regular and 'natural' zoning systems) was not examined empirically, and again it was the lack of time and resources (and the consequent paucity of data for this purpose) which made this inevitable. The relationship between the accuracy of spatial and metric data and the demands and constraints of particular policy contexts has already been mentioned as an untested issue, and again this omission derived from the lack of a range of operational contexts for the research to examine. Further untested methodological issues concerning the generality of the TAE approach will be considered in section 9.2.1. In conclusion it may be stated that the research covered the key issues surrounding the research problem as fully as was practicable, but further research, particularly in relation to the operational issues, would enhance the completeness of the study.

9.2 A CRITICAL APPRAISAL OF THE TAE MAPPING METHODOLOGY

The criteria against which the performance of the TAE mapping methodology should be judged have already appeared in a number of forms earlier in the thesis, but with the emphasis varying according to the needs of the context. For example in Chapter 1.5 the emphasis was on the general context of the research, while in Chapter 3.2 the criteria relevant to mapping techniques were emphasised. The list given below represents an overall summary of the criteria - covering both theoretical and operational issues - against which the general performance of the TAE methodology may be assessed.

(i) Usefulness It is necessary that the mapping methodology be useful and relevant when applied to urban-scale policy contexts where environmentally significant decisions are made.

(ii) Validity The methodology must be based on a theoretically sound foundation.

(iii) Generality The methodology should be as general as possible.

(iv) Spatially comprehensive coverage It is necessary that spatially comprehensive maps be achieved.

(v) Simple, cheap, versatile, readily applied method These qualities are required if the method is to be of practical value to users (such as local government) with tight constraints of budget, resources and time.

(vi) Optimal accuracy and scale It is not necessary for the method to achieve a higher metric accuracy and spatial precision than is required by the urban-scale operational contexts; any additional attention to detail is not cost-effective.

(vii) Aggregation and comparison The method should facilitate the aggregation of indicators, and the aggregation of a given indicator over space, and the comparison of the patterns of different indicators.

9.2.1 A Comparative Assessment of the TAE Methodology

The evaluation of the TAE mapping methodology is presented in terms of the criteria headings given above. It will be noted that such limitations that do exist in the methodology are more apparent in relation to the general criteria of usefulness and generality, and derive from untested issues rather than proven weaknesses.

(i) Usefulness

It has already been stated that an empirical investigation of the usefulness of the TAE mapping methodology in specific case study contexts was not feasible, and so the issue was investigated through a broad discussion given in Chapter 1.1, in which it was seen that the methodology is in principle applicable to a wide range of contexts. It was noted that unlike the methodologies incorporating a 'potential surface analysis' (p.s.a.) approach (e.g. AMMER 1976, KARPE and SCHOLZ 1976, SOUTH YORKSHIRE COUNTY COUNCIL 1978a) the TAE methodology is not a decision aid as it stands, since the value judgements and evaluatory criteria are specifically excluded. While for this reason it is less directly useful in the contexts for which the 'p.s.a.' methods were designed, it is possible to envisage the TAE methodology as the technical mapping component in a prospective 'p.s.a.' methodology. Thus it is still possible for the TAE methodology to be integrated with evaluatory criteria to achieve a 'psa' approach, while the explicit separation of the mapping method from value judgements means that it is also applicable to contexts where evaluation is not appropriate.

An integral feature of the TAE methodology is the classification of the study area through a typology of urban fabric parameters, and the association of the resulting urban fabric types with typical environmental conditions. This classificatory approach is particularly useful in planning contexts since it relates environmental conditions to the 'building blocks' of the urban systems which planners aim to control and develop. Moreover such an approach facilitates a 'dynamic' rather than a purely 'static' or descriptive mapping methodology, since conditions are predicted from independent parameters which may be altered in accordance with prospective future options or alternatives. It should be noted that the South Yorkshire case study of the Ammer methodology resulted in recommended modifications to the method to allow a 'dynamic' approach to be adopted and to include a relationship with land use (SOUTH YORKSHIRE COUNTY COUNCIL 1979).

(ii) Validity

The theoretical validity of the TAE mapping methodology relies on the causal model proposed by WOOD et al (1974) and others, namely that the environmental conditions of an area are determined by the 'degree and type of land use activity' to be found there. Wood et al refined this hypothesis into a 'subregional wastes-pollution model' which is in principle more robust than the TAE methodology since it is based on an explicit two-stage pollution process, involving firstly the relationship between urban activities and the generation of wastes, and secondly the relationship between the generation of wastes and the occurrance of pollution. The TAE methodology subsumes these two distinct processes into the one relationship directly associating urban fabric activities with environmental conditions. While this simplifies the methodology it does somewhat constrain its generality since the causal effect of urban fabric types upon environmental conditions must be inferred, in this case from empirical data specific to the WMMC and particular to the period of observation. However this is in practice no different from the approach used to validate and calibrate Wood's model, for while the mechanism of that model is more explicit, no empirical means was found for specifying, quantifying, and calibrating the two individual stages. Thus the advantage of the more detailed mechanism lies simply in the clearer theoretical understanding that may be applied to the development of empirically-testable hypotheses. Examples of this are also to be found in this thesis, in Chapter 4.3 in connection with the devising of the road network density parameter, and in Chapter 6.4 in the reformulation of urban fabric types for use in the diffusion model.

The theoretical basis of the TAE methodology requires that TAE zones be 'self-contained'; that is, between-zone transfers should not be significant enough to violate the principle of 'functional zone independence'. As already stated the validity of this in the case of the TAE methodology is hard to assess empirically; this is due firstly to the limited amount of data that it was feasible to collect, and secondly to the nature of the urban fabric, which is such that area types seldom occur independently (i.e. randomly) - at any rate at the spatial scale defined by the size of the TAE (see also under 'optimal zone size').

Thus the validity of the assumption of functional zone independence was tested only as part of the overall empirical test of the validity of the TAE methodology, namely the test of the 'TAE hypothesis' that the environmental conditions of zones are significantly associated with their TAE type. As already stated, the hypothesis was validated in each of the four case studies, and this result was taken as a general empirical validation of the TAE methodology insofar as its application as a mapping method is concerned.

(iii) Generality

The generality of the TAE methodology should be examined from two viewpoints: firstly, can it be applied to a truly comprehensive range of environmental attributes, and secondly, can it be applied to all types of urban area. The generality of the methodology is open to scrutiny both for theoretical reasons and also because of the limited amount of empirical analysis that was feasible.

Chapter 4.1 discussed the theoretical factors limiting the applicability of the TAE methodology to ambient environmental attributes, where 'ambient' was understood to refer to attributes generally measurable to some degree throughout an urban study area. Two classes of non-ambient attribute were identified, involving those whose nature is linear rather than areal (e.g. water quality of rivers and canals, and traffic-related air pollutants), and those which are highly localised around particular, isolated sources (e.g. aircraft noise, heavy metal air pollution). The major reasons for their exclusion from the methodology were the problems surrounding the design and operation of spatial indicators for the linear attributes, and the development of spatial urban fabric parameters with which a causal association might be hypothesised. However it cannot be argued that such non-ambient attributes are intrinsically necessarily excluded from a possible extended version of the TAE methodology tested in this research, provided that further research was undertaken to develop the indicator methodology. Indeed the only type of environmental attribute necessarily excluded from the TAE methodology approach is that which exhibits an essentially random spatial pattern, and for which it is therefore impossible to identify causal 'predictor' parameters.

The more general type of TAE methodology has not been tested in this research and in consequence the generality of the validated methodology is limited to ambient attributes. Examples of such attributes are given in Table 9.3

Table 9.3 Examples of Environmental Indicators That Might be Mapped Through the TAE Methodology

ENVIRONMENTAL SECTOR	INDIVIDUAL ENVIRONMENTAL ATTRIBUTE
AIR	Sulphur dioxide Smoke (total suspended particulates) Grit and Dust Lead and other heavy metals (possibly) Carbon monoxide (possibly) Nitrogen oxides (possibly)
LAND	Soil contamination by heavy metals Public open space Derelict/waste land Area appearance
WATER	None
NOISE	Ambient noise
MISCELLANEOUS	Ecological factors Conservation potential Ground subsidence (possibly)

The fact that the TAE methodology has only been tested in the WMMC means that its general applicability to all types of urban area has not been examined empirically. Specifically, it has not been possible to answer several key questions in this respect; namely; can the TAE classification be applied universally in the UK? what are the upper and lower limits to the size of urban area for which it is applicable? can the methodology be extended internationally? or is it restricted to industrial conurbations of a particular kind, similar to the WMMC? Can it be extended to areas which are largely rural in character? How robust are the TAE prediction models? Should a recalibration be made in each study context; How stable are the model specifications and calibrations over time, even within the WMMC? These many questions concerning the spatial and temporal generality of the method cannot be answered without the evidence of further research. Such research should concentrate specifically upon the application of the TAE methodology to other industrial conurbations, to conurbations (like Greater London) not dominated by industry, to a range of sizes and types of urban area, and to the WMMC again after a suitable period such that significant changes in the specification and/or calibration of the models over time might be assessed.

(iv) Spatially comprehensive coverage

The TAE methodology provides a means of achieving spatially comprehensive coverage of a study area, assuming that spatially comprehensive urban fabric data are available. The thesis has shown that essentially only three methods exist for achieving spatially comprehensive environmental data: comprehensive spatial measurement (either of points or area units), point-receptor prediction requiring valid, calibrated models and comprehensive spatial data on source locations and strengths, and area-based prediction such as that underlying the TAE methodology. WOOD et al (1974) have found that comprehensive spatial measurement using secondary source data is rarely possible due to the frequently spatially-incomplete nature of the data, while administrative bodies such as SOUTH YORKSHIRE COUNTY COUNCIL (1978 a, b), CHESHIRE COUNTY COUNCIL (1977) and MERSEYSIDE COUNTY COUNCIL (1976) have shown the extensive commitment of time and resources that is necessary if direct comprehensive measurement of a number of environmental attributes is undertaken. SOUTH YORKSHIRE COUNTY COUNCIL (1978b), PRABHU and CHAKRABORTY (1978) and GIFFORD and HANNA (1973) have all pointed to the complexity and questionable validity of using point-receptor prediction methods in large urban areas with a multiplicity of sources, and in any case there is a limited number of environmental attributes for which such theories may be applied. The TAE methodology has a two-fold advantage over the alternative approaches: (a) the comprehensive spatial coverage is derived from comprehensive spatial (urban fabric) data already readily available within most local authorities, and (b) the measurement exercise is reduced to a survey of a small number of 'sample frame' areas. As a result it is the most parsimonious comprehensive mapping technique available; this fact is of critical importance since it may place environmental mapping within the capabilities of low-resource studies and organisations for which the use of the alternative techniques would otherwise prove to be unfeasible.

(v) Simple, cheap, versatile, readily applied method

The TAE methodology was specifically designed with the above requirements in mind. Some points have already been raised.

The method is simple; a relatively simple classification of the urban fabric is used (as compared with the more complicated factor and cluster analysis techniques), and the transposition of urban fabric to environmental data requires only the manual application of a tabular model - a computer is not therefore necessary.[1] A simple, regular, grid-square zone configuration is used to represent the spatial data.

The method is cheap because comprehensive spatial coverage is achieved by means of readily available urban fabric data, and measurement is reduced to a 'sample frame' covering only 7% of the study area (note that the comprehensive measurement process adopted by SOUTH YORKSHIRE COUNTY COUNCIL 1978a,b proved to be the most resource-demanding part of the whole project). The minimal computational demands also reduce the cost of the method.

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1. The thesis shows of course that a computer-based analysis was required in this study to calibrate the TAE prediction model.

The method is versatile; the case studies have shown that it may be applied to both point- and area-based indicators with either ordinal or cardinal data properties. A wide range of environmental attributes may be covered despite the fact that the method tested here is only applicable to those which may be classed as 'ambient'.

The method is readily applied because the urban fabric typology is deliberately expressed in terms of data that are readily available to local authorities. Calibration has been achieved with the aid of simple, speedy field-survey techniques or readily available secondary source data.

(vi) Optimal accuracy and scale

The method has been designed to achieve the optimal accuracy and scale for strategic, urban-scale planning contexts, although it has only been possible to make a generalised and broadly theoretical discussion owing to the lack of specific operational case study contexts. The TAE size was chosen on the best available evidence, to achieve 'functional zone independence'. The choice of five environmental categories is comparable with the number used in other contemporary studies - in fact it is interesting to note that the South Yorkshire case study of Ammer's method resulted in a recommendation to reduce the number of mapped categories from ten to five because in general the accuracy of the data could not support the higher number (SOUTH YORKSHIRE COUNTY COUNCIL 1979).

(vii) Aggregation and comparability

Because the TAE methodology provides a common spatial base for the representation of the individual attribute indicators, it provides a standardised representational method which facilitates the aggregation and the comparison of the individual attribute patterns. This is an advantage over those studies where different representational techniques are used for the individual indicators - for example CHESHIRE COUNTY COUNCIL (1977) attempt to compare isopleth air pollution maps with choropleth maps of land-based parameters. In these instances even the visual comparison of maps is difficult to conduct, while the quantitative aggregation of the spatial data presents highly technical methodological problems.

It is evident that the TAE types are the key elements facilitating aggregation and comparison of conditions. An example of how the TAE types may be used to provide descriptive data covering the range of urban fabric types and conditions is given in Appendix D, in which illustrative 'monographs' of each TAE type are presented. Such information, possibly enhanced by more elaborate detail on a broader range of environmental (and possibly socio-economic - see 9.2.3) conditions in each type, could provide the basis for the concise expression of the descriptive, contextual data for use by planners, elected representatives and the public, in discussion and consultation exercises involving a wide range of strategic planning policies.

9.2.2 Summary - An Overall Appraisal of the TAE Methodology

It has been seen that in respect of the key criteria for broad, urban-scale mapping methods the TAE methodology is a theoretically sound, operationally useful approach offering considerable advantages over alternative contemporary methods. Furthermore the TAE methodology goes beyond the mere facilitation of spatial data. The validation of the key hypothesis upon which it is based - namely a causal association between environmental conditions and certain determinant parameters of the urban fabric - makes a valuable contribution to urban theory in general. The hypothesis is not in itself original, indeed it was seen to be central to the general modelling approach adopted by WOOD et al (1974), and much earlier in individual attribute studies (e.g. MEETHAM 1945, POOLER 1961). The following points however do appear to be original:

(i) the attempt to cover a wide range of environmental attributes with a single urban fabric classification, i.e. with a single set of TAE types;

(ii) the explicit definition of two independent urban fabric parameters reflecting the 'degree and type of land use activity' within an area, and the explicit definition of the composition and spatial characteristics of the parameter categories;

(iii) the use of readily available urban fabric data as the basis for the definition of categories (TAE types) and the resulting spatially comprehensive environmental predictions;

(iv) the large number (19) and comprehensive range of the area types defined by the parameter categories;

(v) the explicit formulation and subsequent application of the area-based (TAE) spatial prediction models;

(vi) the resulting standard spatial and area-type basis for the mapping method;

(vii) the theoretical rigour with which the methodology was tested in the research;

(viii) the extent to which the results enhance current knowledge of the relationship between environmental conditions and the urban fabric, and allow a 'dynamic' mapping method to be achieved.

The key to the whole approach is seen to be the concept of the TAE itself, since it provided not only the testable articulation of the key hypothesis, but the operational basis for the resulting mapping methodology.

9.2.3 Proposals for Further Research

The foregoing sections of this chapter have identified three important areas where further research would prove useful; the testing of a range of operational policy contexts, the extension of the method to non-ambient attributes and the testing of the method in other urban areas and over a period of time. Two other topics are recommended for further research.

The first of these concerns the 'road network density' parameter, a key element in the definition of the TAE types. Chapter 4 stated that the parameter was simply a readily-obtained surrogate for 'traffic density', the parameter with respect to which the TAE hypothesis was actually founded. In addition to being a surrogate parameter, 'road network density' was seen to be expressed in somewhat arbitrary, ordinal units of 'network node density'. It is therefore recommended that a more direct, precise measurement of traffic density be developed as the basis for the TAE classification; although involving more complex methodological and practical problems an appropriate indicator for the parameter would still be readily obtainable from standard County authority traffic network assignments. It would also enhance the theoretical basis of the hypothesis if the relationship between traffic density and urban density was investigated more fully. A more systematic approach to the 'density' parameter could be expected to result in a higher explanation of spatial environmental variation, and this might be furthered by subclassifying some of the land use categories. For example, the industrial category could be broken down by industrial class, and the residential category by housing age. However it should be noted that some of these subclassifications will be subsumed, through correlation, in the 'mixed' categories and the traffic density classification[1]; moreover any improvement

1. For example, the oldest residential areas tend to be found in association with high traffic densities.

in the explanatory power of the prediction models must be weighed against the increasing complexity of the classification system and the difficulties in obtaining the data through which to apply it (for example, spatial data relating to industry classes).

The studies by WOOD et al (1974) and KARPE and SCHOLZ (1976) both make reference to the detection of a relationship between environmental conditions in general, and certain socio-economic characteristics of the urban pattern (for example employment type, car ownership, access to facilities such as shopping, education, health and public transport). JURUE (1977a) have also hypothesised that a relationship may exist between environmental conditions and a whole range of factors of the urban fabric built form, in a more explicit (possibly mathematical) association than that proposed in the TAE methodology. In addition it would be useful to compare the environmental pattern with a map of population density in order that an assessment of pollution 'exposure' profiles might be achieved.

Clearly such issues are of direct concern to planners especially if, as suggested by Wood et al, an association of poor conditions, both environmental and social, is evident, leading to situations of compound deprivation. It is therefore recommended firstly that the results of the research be compared with the spatial patterns of social indicators such as those given above, in order to test the validity of the hypothesis that social and environmental conditions are significantly spatially covariant over the WMMC; in addition the hypothesised association between environmental conditions and urban fabric built form characteristics as given in JURUE (1977) should be tested. Secondly it is recommended that research be undertaken to test whether the TAE methodology might be extended to the mapping of social as well as environmental indicators, for the detection of spatial covariance between environmental and social conditions implies that this might be possible.

APPENDIX A

BACKGROUND TO THE CASE STUDY: URBAN FABRIC DATA AND SURVEY METHODS

A.0 INTRODUCTION

This appendix provides the technical details of the methods by which urban fabric data, derived mainly from secondary sources, were adapted and compiled in order to achieve a comprehensive urban fabric 'base map' of the WMMC expressed in terms of TAEs.

Details are then given describing the survey methods employed in the research, the particular objects of which were to obtain empirical data on ambient noise levels and area appearance conditions in a selected sample of TAEs.

The appendix is in five parts. The first three concern the techniques adopted in obtaining the urban fabric data for the WMMC case study area, the final two the sampling method and data collection exercises appertaining to the field survey. It is emphasised that the appendix should be consulted in connection with cross-referenced sections in the main text and other appendices, in order to obtain a comprehensive coverage of the case study issues.

A.1 URBAN FABRIC DATA: LAND USE

Section 4.3.1 of the main text referred to the fact that land use data for the majority of the WMMC area were directly available from secondary sources, the pre-1974 County Borough Structure Plan Reports of Survey. These gave data covering the conurbation, Coventry, and some of the outer areas, updated to, on average, 1972. Some of the urban fringe areas, notably around Stourbridge in the South-West, and Aldridge/Brownhills in the North, and also the large Green Belt sector in Solihull (formerly parts of Staffordshire, Worcestershire and Warwickshire respectively) were not covered by the available land use data and here it was necessary to construct land use maps using 1:10,000 Ordnance Survey maps and local knowledge. In these latter cases it was possible to designate land use expressly in terms of the four basic land use activity categories devised especially for the research and given in Table 4.2 in the main text. The secondary source data were expressed in terms of the land use categories given in Table 4.1 in the main text, for 0.1 X 0.1 km grid square units, each unit being allocated to one of the land use categories in Table 4.1 on the basis of the most predominant land use within it (by contrast, the land use data derived from the O.S. maps were expressed over spatial zones whose boundaries followed the continuous boundaries of the land use types as precisely as possible).

By these means a base map of land use data for the WMMC was obtained which was as spatially and typologically detailed as possible. This was then transformed into a base map expressed in terms of TAE land use types (as given by Table 4.3 in the main text) and TAE grid square zones (i.e. 1.25 X 1.25 km). The procedure for this involved overlaying the TAE grid upon the base map of land use data, and categorising each TAE in turn. The allocation of TAE land use categories to zones was achieved using criteria which were as quantitative as possible, in order to enhance the objectivity of the classification method: each TAE was taken individually, and the percentage of its land area falling into each of the four basic land use activity types were estimated, in units of 10%. No finer accuracy was considered to be reliable in view of the particular land use data available and the measurement method used. This measurement method involved visual assessment aided by a sub-TAE grid, divided into 16 units each therefore approximately equivalent to 0.1 sq. km. A TAE land use category, selected from the classification given in Table 4.3, was then allocated to the TAE using the following guidelines as general criteria: 'pure' types were designated wherever one particular land use activity type occupied 80% or more of the TAE zone, or where one activity exceeded the next most predominant by 50% or more of the zone area; in all other cases, 'mixed' types were defined, identified by the top two most prevalent activities, except in the case of the commercial activity category, where the inclusion of a commercial mix in the category was considered wherever it occupied 10% or more of the zone. In this way TAE land use types (Code 0-9) were allocated to each TAE in the WMMC; it should be noted that the use of quantified criteria, while an improvement upon the generally qualitative methods of other research (e.g. BSI 1975, WARREN SPRING LABORATORY 1974), does not remove the essential arbitrariness of the process.

Naturally, since the TAE base map forms the spatial basis upon which the environmental patterns are predicted, the accuracy of the environmental patterns is critically dependent upon the accuracy of the TAE base map. Three possible sources of inaccuracy in the land use element of this base map were evident;

(i) in the estimation of land use data for those areas where properly surveyed secondary source data were not available;

(ii) in the cartographical manipulations through which the various secondary source maps were transposed to a single land use base map;

(iii) in the visual technique for estimating the percentage of each TAE occupied by each basic land use activity type.

No particular method was available for assessing either the extent of these errors or their effect upon the accuracy of the TAE mapping methodology. A simple, qualitative appraisal was made possible by the field survey, for in the site visits of the sample TAEs the land use type observed 'on the ground' could be compared qualitatively with the land use category allocated to the TAE on the basis of the mapped data.

In no case was there found to be sufficient evidence to suggest that the sample TAE was incorrectly classified. The base map of land use data, and the final TAE map, are shown in Section A.3.

A.2 URBAN FABRIC DATA: ROAD NETWORK DENSITY

Section 4.3.2 of the main text describes the rationale and hypotheses behind the choice of 'road network density' as the second classificatory parameter. This parameter may be operationally defined (and therefore measured) in a number of ways - for example measures such as 'total road length per unit area' or 'mean link length' might be used. The operational problem is to select a simple measure for which data might be readily obtained, comprehensively covering the whole WMMC area. It was mainly in response to this demand that 'network node density' was chosen.

The data for this measure were readily obtainable from the 1976 base year transportation network for the WMMC (WEST MIDLANDS COUNTY COUNCIL 1977), and measurements consisted simply of the total number of network nodes within each TAE zone. Such nodes were located either at junctions in the transportation network or at network traffic loading points (usually the location of these corresponded to actual road junctions not represented on the simplified transportation network), and consequently the assumption that 'network node density' was an acceptable indicator of the 'real' road network density was plausible.

Strategic transportation networks are of course large-scale simplifications, and the use of this secondary data source as the basis for a measure of the second predictor parameter constrained the level of spatial detail that could be achieved in the final TAE map, because of the general spatial density of the nodes concomitant upon the network scale. Thus at the preferred TAE size (0.5 X 0.5 km, as discussed in section 4.2) the vast majority of TAE zones would contain only one node or none at all -

in other words the 'node density' indicator would not be an effective differentiator of zones. Thus it was necessary to increase the TAE zone size until a broader distribution of measures was obtained, thus allowing zones to be differentiated, and therefore classified, with respect to their indicator values. Since the use of road network density as a classificatory parameter for environmental conditions appears to be unique, there was little available evidence, even at the hypothetical level, to suggest how effective it might be as an independent differentiator variable - in other words, how much spatial variance in environmental conditions it explains. There was consequently no rational criterion available upon which to determine how many categories the node density parameter should be divided into in order to maintain consistency relative to the ten land use categories. A pragmatic rationale was therefore adopted, leading to the selection of three categories, termed 'dense' (A), 'medium' (B), and 'sparse' (C), according to the relative values of the node densities encompassed. Three categories were considered to be enough to reflect the basic relationship while not stretching the hypothesised explanatory power of the node density indicator too far. The procedure for selecting the appropriate zone size and definition of categories was somewhat arbitrary; zone size was increased from 0.5 X 0.5 km in steps of 0.25 km, noting each time the distribution of node density values; at the value 1.25 X 1.25 km, the distribution histogram given in Fig. A.1 was obtained, and the dispersion of values was considered to be sufficient to allow three distinct categories to be defined; the demarcation of the categories, shown in the figure, was essentially arbitrary with the main criterion being that the proportions of the WMMC area in each category should be of the same order of magnitude.

Having selected the appropriate zone size and classification, each TAE in the WMMC was allocated a 'network density' category (code A-C)

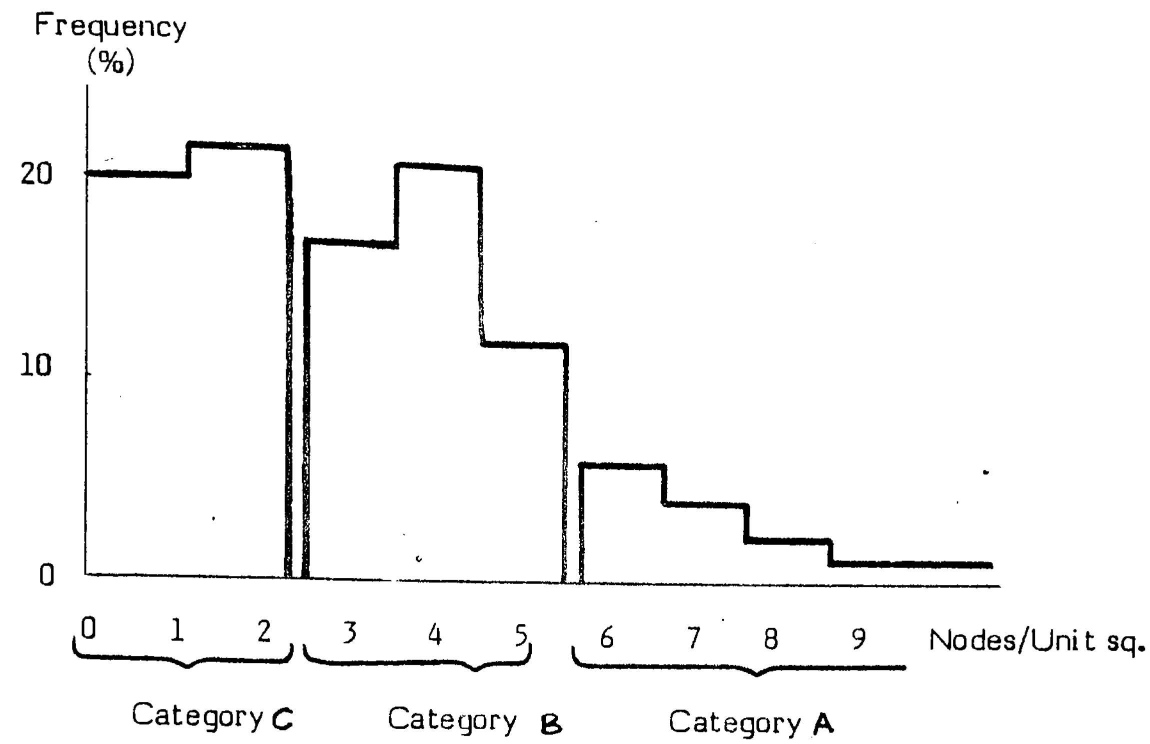


Fig. A.1 Histogram showing node density frequency distribution for the WMMC.

appropriate to its network node measure. In contrast to the land use classification, it cannot be argued that the road network density classification method is based upon objective and 'absolute' criteria. This follows from the fact that the base data (the transportation network node density) are arbitrary measures whose values are entirely a function of the network scale and other transportation-oriented criteria. The argument for applying the data to this research is that the distribution[1] of these values is not arbitrary, but reflects the distribution of the density of the actual WMMC road network; however since the measures themselves are arbitrary the demarcation of the categories is also arbitrary, and particular to the WMMC transportation network. Thus the main weakness of the method is that it is not repeatable (in the sense of being able to define comparable categories) in other study areas, and also that the categories themselves are essentially only ordinal. Chapter 9.2 in the

1. Including both spatial and statistical distributions.

main text describes the need for further research to develop an objective, standardised, repeatable basis for the classification of road traffic density.

A.3 GENERAL DESCRIPTION OF THE WMMC

Section 4.3.3 of the main text describes how landuse and road network density act as independent parameters in a two-dimensional matrix to define the comprehensive set of urban fabric TAE types. With ten land use categories and three network density categories, it was theoretically possible that 30 TAE types existed if the two parameters were independent.

The TAE type base map, from which all the predicted environmental patterns were obtained by direct transformation using the TAE prediction models, was formed by superimposing the TAE land use map and the TAE network density map, thus classifying each TAE into a 'cell' in the two-dimensional TAE type matrix. The statistical frequency distribution of the 575 TAEs amongst the 30 possible TAE types is shown in Table 4.4 in section 4.3.3 of the main text. The fact that a certain functional relationship does exist between land use and road network density (for instance, predominantly commercial areas are not found in conjunction with sparse networks, nor areas of predominantly open space with dense networks) is evidenced in this frequency distribution, and the main text discusses the fact that the actual number of TAE types considered in the research was reduced to 19.

In order to achieve a visually informative display of the urban fabric pattern of the WMMC a simplified land use data base map (Fig. A.2) and a TAE-based road network density map (Fig. A.3) are presented. These maps help to illustrate the following description of the geographical characteristics of the WMMC.

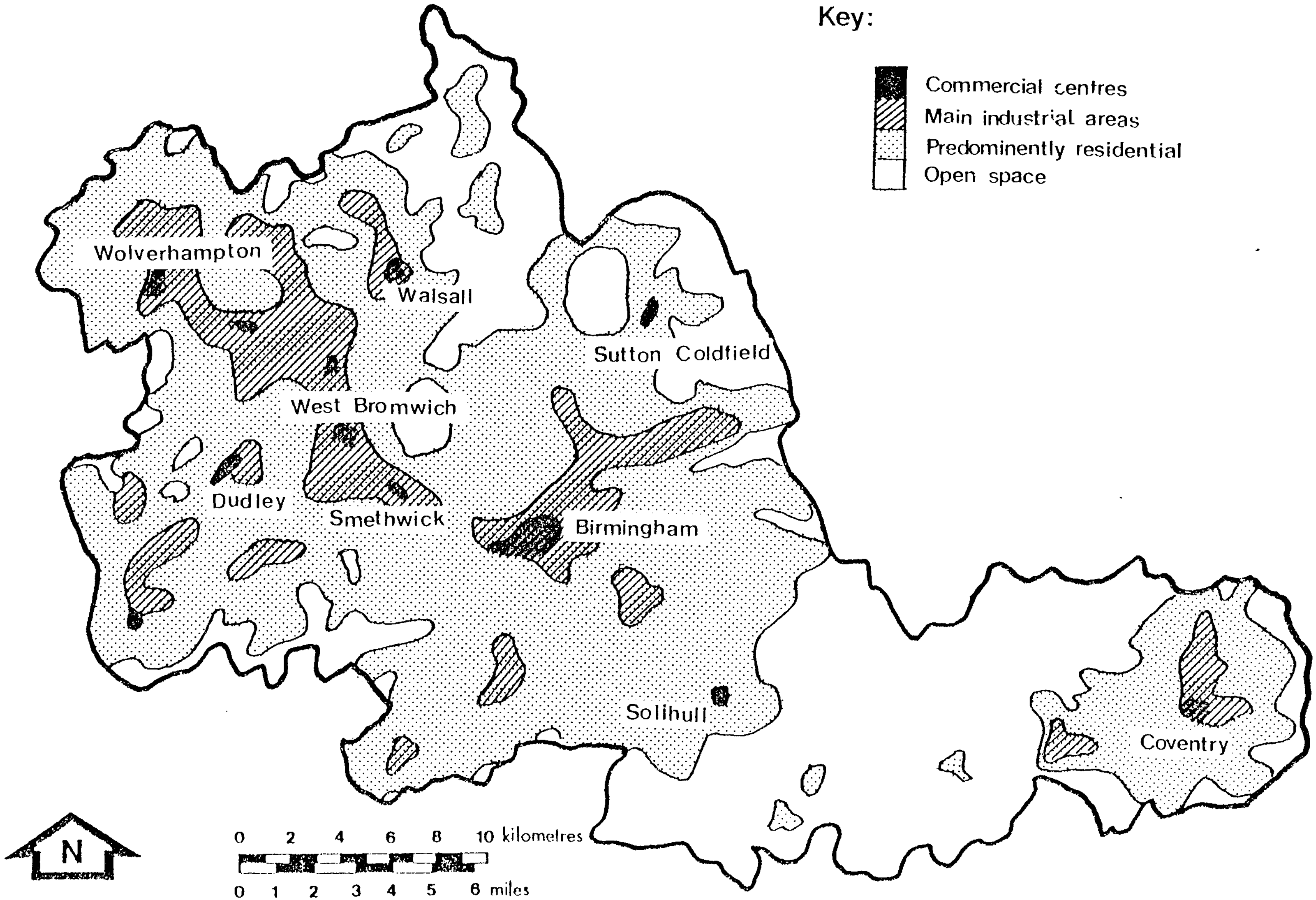


Fig. A.2 Map showing the principal land use types and urban centres in the WMC

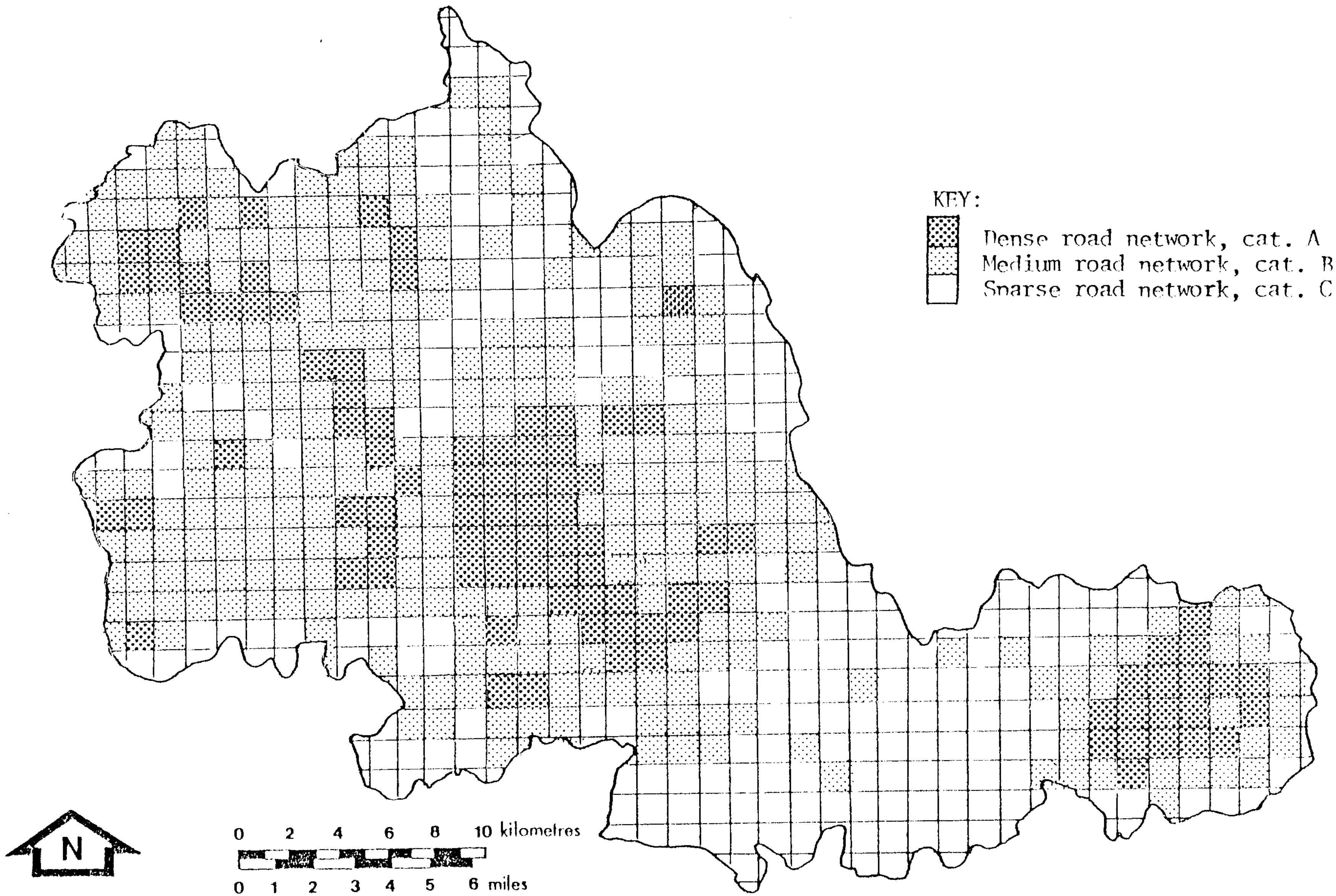


Fig. A.3 Map showing the pattern of road network density categories in the WMMC

The WMMC covers an area of approximately 900 sq. km., and with a population in the region of 3 million it is clearly an important area due to size and population. The new Metropolitan County was formed in the local Government reorganisation of 1974 from parts of Warwickshire, Worcestershire, Shropshire and Staffordshire. It is centred on Birmingham, the major regional centre of commerce and the second largest city in the UK, and includes the whole of the West Midlands Conurbation as well as Coventry to the east.

The industrial base is grounded in the manufacturing industry, with Birmingham and Coventry forming the focus of the UK motor vehicle construction industry. Engineering is also important in these two cities. To the west of Birmingham is the 'Black Country', comprising the dominant industrial areas of the conurbation in which iron foundries proliferate, especially in the Smethwick and Wolverhampton areas, while a large British Steel Works is currently situated at Bilston, and the leather industry stillfeatures strongly in Walsall. In addition there is an abundance both in the Black Country and Birmingham of small-industry metal trades in the secondary sector, with brass being a common medium. Old and for the most part disused mining areas are to be found in the Northern and South Western parts of the conurbation. In general the most significant industrial areas are those to the Northeast of Birmingham and in the broad band to the west, passing through Oldbury, Smethwick and West Bromwich to the Bilston area, then striking Northwards in three prongs, towards Wolverhampton, Walsall and the Darlaston/Willenhall area. To the Southwest of this are industrial areas stretching past Dudley to Cradley Health, Lye and Old Hill.

Residential areas dominate the land use activity in Birmingham, while Halesowen, Southwest Wolverhampton, and areas around Walsall and Coventry are also important. Birmingham city centre dominates the commercial activity of the WMMC, with Wolverhampton, Coventry, Walsall and Dudley in a second league. Open space is principally restricted to the Green Belt wedge in the District of Solihull, separating Birmingham and Coventry; a second belt is significant however and almost bisects the conurbation, driving Southwestwards from Sutton Park, Barr Beacon and the Countryside past Aldridge, down into the Sandwell Valley; to the southwest again it reappears at Rowley Hills to the west of Warley and Halesowen, merging with the countryside around the Clent Hills to the Southeast of Stourbridge. Topographically the County is a low, undulating plateau dissected in the North by the East-flowing River Tame, in the South by its tributaries the Cole and Blythe. A ridge at about 250m in altitude extends from Dudley through Rowley Hills to Warley; much of the remainder of the County lies at heights of between 100-150m.

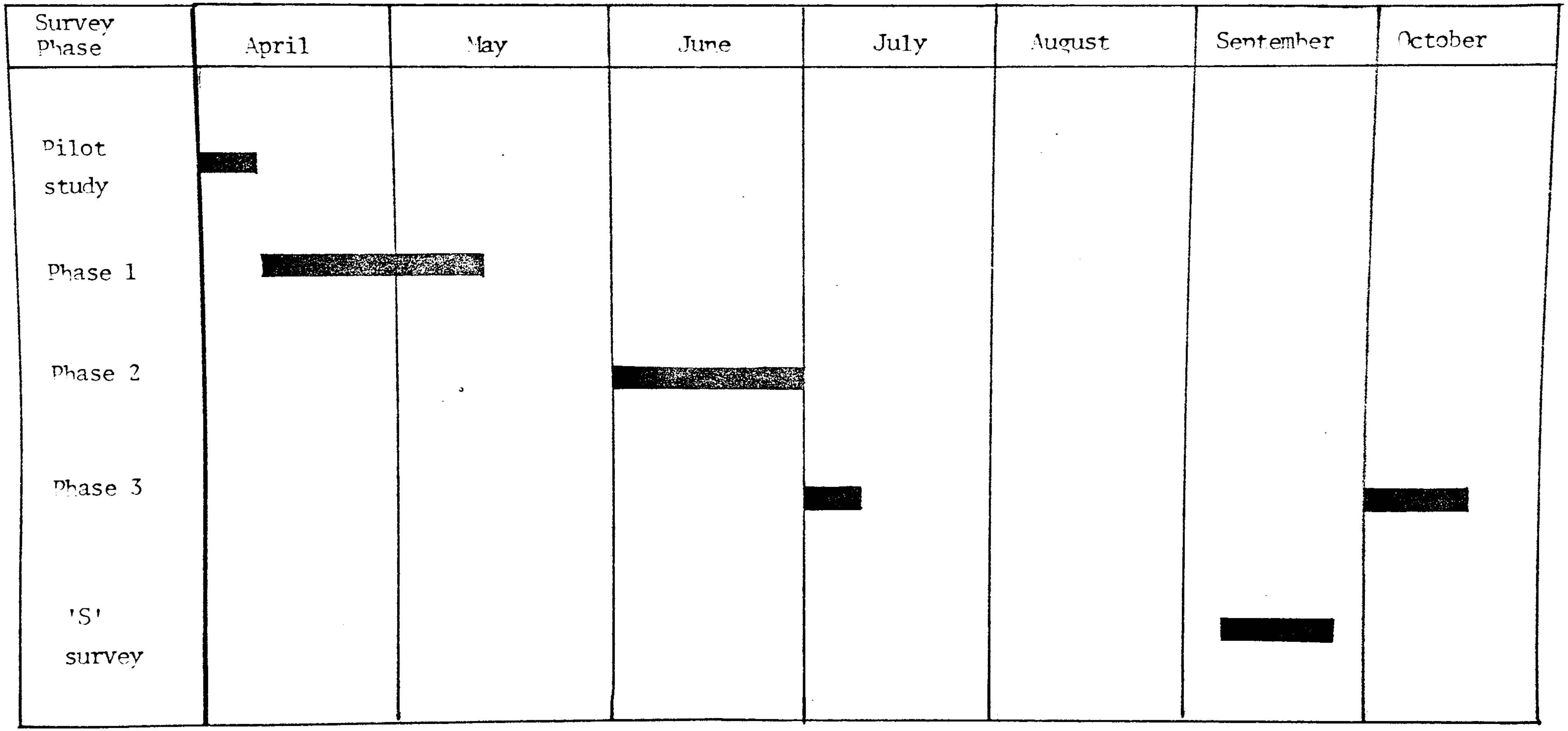
A.4 GENERAL DESCRIPTIONS OF THE FIELD SURVEY METHOD

The field survey was conducted in order to obtain empirical measurements of ambient noise and area appearance conditions upon which the TAE methodology could be tested. This use of the data is discussed extensively in the respective chapters (5 and 7) of the main text. Other environmental information was also obtained, as described in the following section A.5 on data collection.

The field survey was conducted in three phases over a total period of some six months. In Phase 1, one TAE was sampled from each TAE type, giving nineteen sample TAEs. Phase 2 involved further sample TAEs in order to test the variability between sample TAEs of the same type; eight TAE types were chosen for a second sample, and of these, three types were chosen for a third sample, giving eleven Phase 2 samples in all. A return survey to seven sample TAEs, was made in Phase 3; the seven return samples were chosen from those units already sampled in Phases 1 and 2, and the return survey was conducted some 2-6 months after the original survey (the purpose of Phase 3 being to investigate the repeatability of observations over time, as discussed in Sections 5.3.2 and 5.4.1). The factors dictating these sample sizes were essentially pragmatic, the main criteria being to ensure that the conditions within a sample of each TAE type were observed (hence the 19 TAEs in Phase 1) and that checks were made to allow an assessment of the representativeness of a single sample TAE to be made, with respect both to variations amongst TAEs of the same type and to variations in an individual TAE's conditions over a period of time (these being the objectives of Phases 2 and 3). The number and TAE type of the TAEs sampled in Phases 2 and 3 reflect the use of a representative sample frame to achieve data for these purposes from the smallest possible sample, in order to minimise survey time. Fig. A.4 shows the dates upon which surveying took place during the period March-October 1977 (the special 'S' survey of ambient noise, described in Appendix B, is also included); it is evident that the field survey was a time-consuming exercise and it was for this reason that sample numbers were kept to a minimum. Fig. A.5 shows the location of all sampled TAEs, coded by the survey phase(s) in which visits took place. Spatially the selection was random (arbitrary), but with an overall consideration towards maintaining an even distribution of samples over the WMMC area.

Within each sample TAE, survey sites were selected using cluster sampling and sample densities as discussed in Section 5.3.1 of the main text. Each of the five clusters in a given TAE is termed a 'location'. The surveyor proceeded from location to location by vehicle (a survey van), and from site to site within each location on foot. The central site of each location had therefore to be accessible to the vehicle, and the three surrounding sites had to be accessible to the surveyor on foot. Constraints of practicality thus required modifications to be made in the original designation of sites determined solely by the use of the random 'master' overlay pattern shown in Fig. 5.3(b) in the main text. An example

Fig. A.4 Diagram showing the dates when the field survey was conducted (1977)



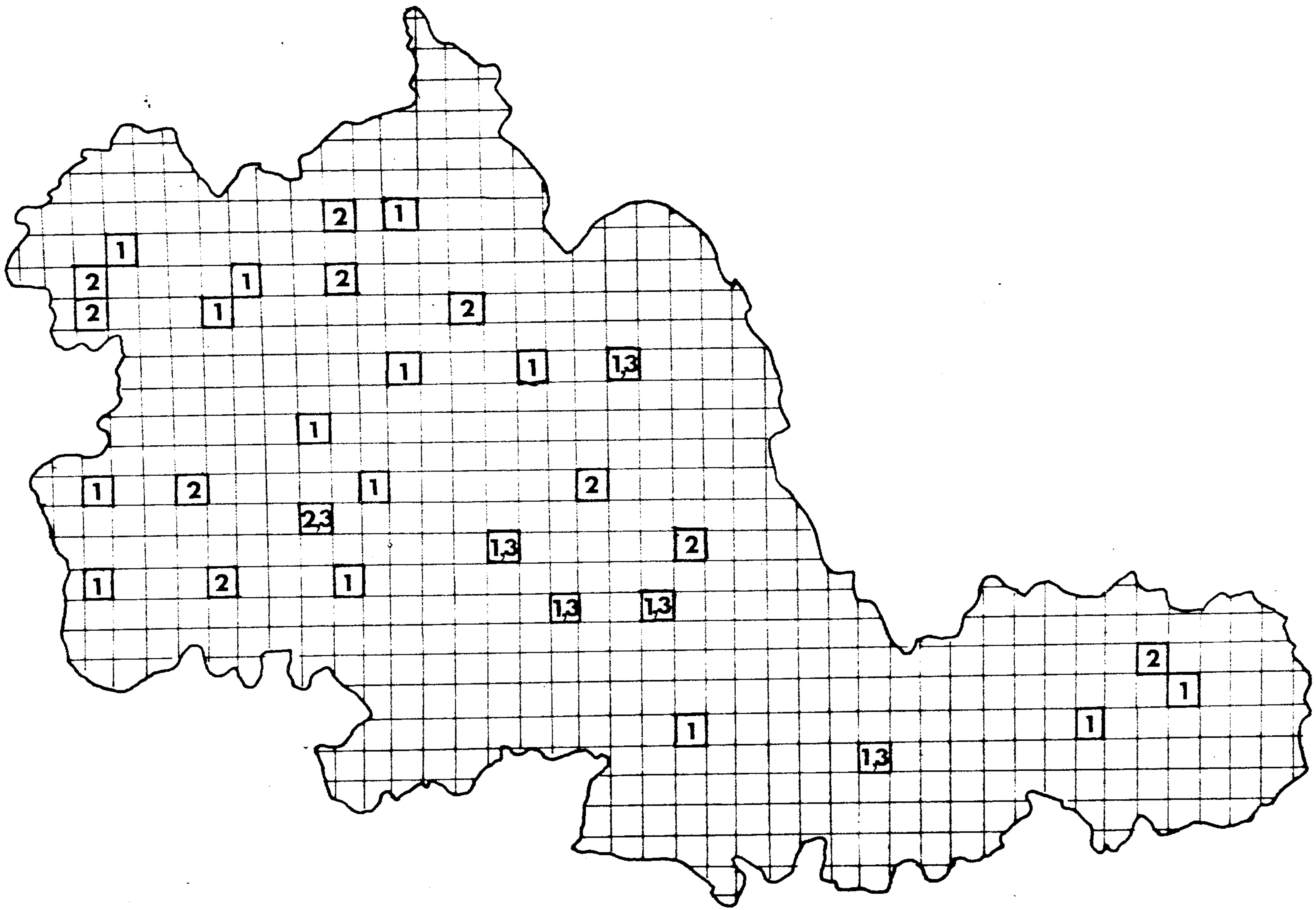
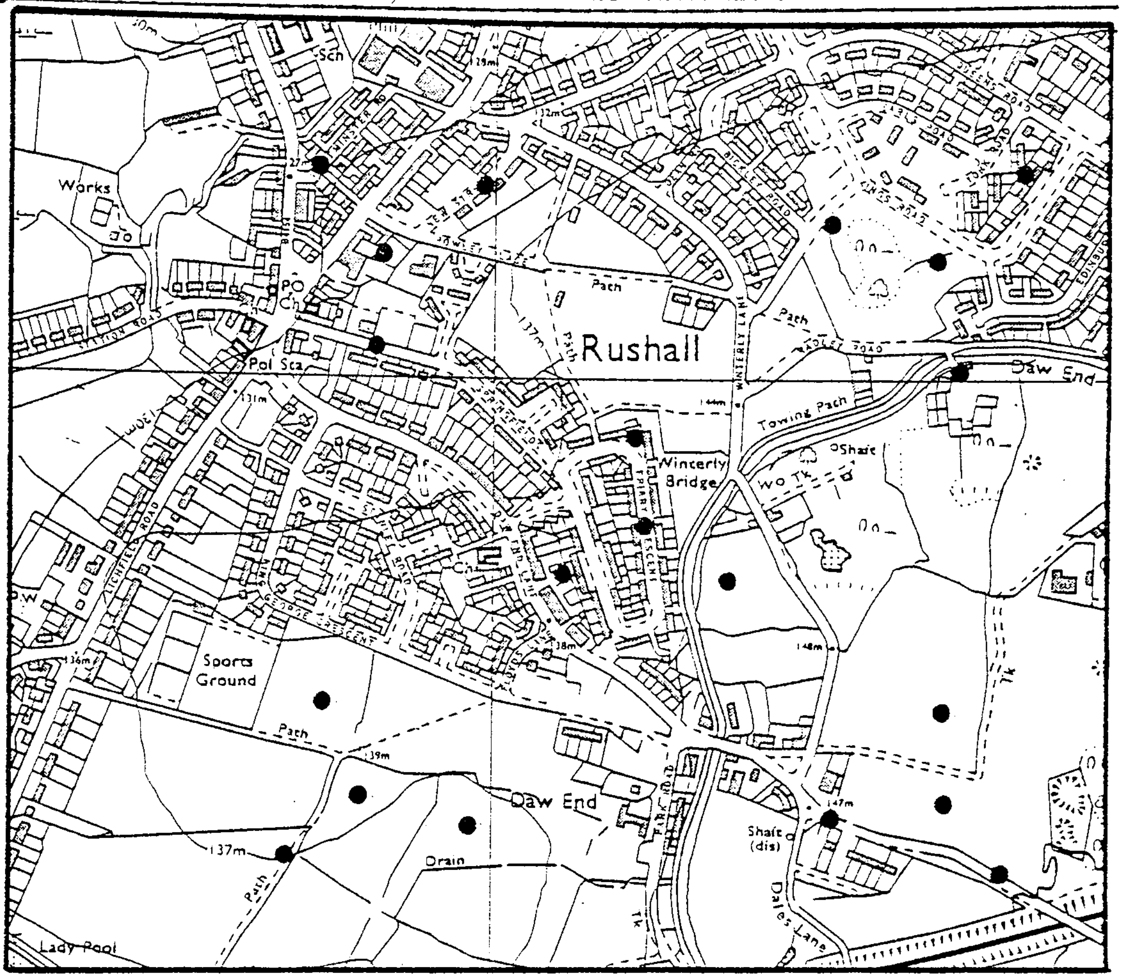


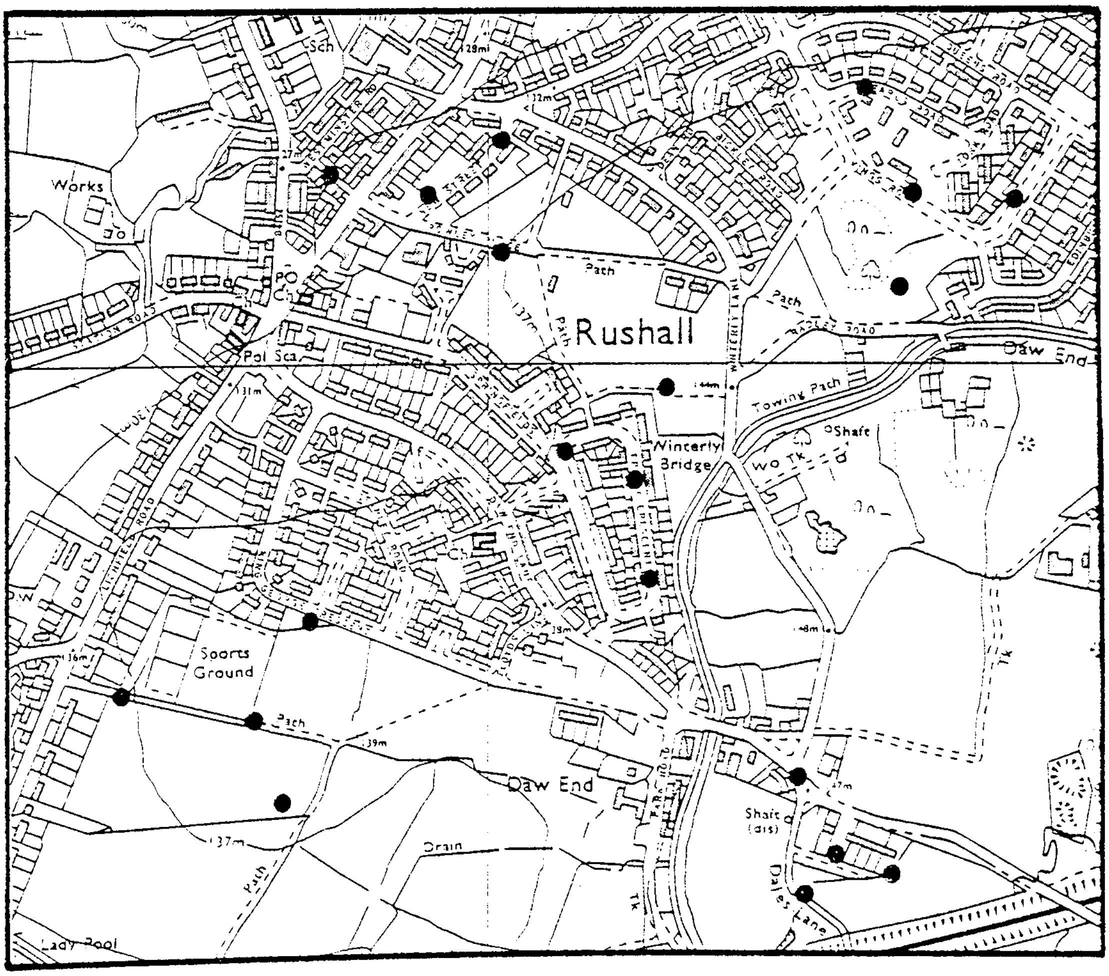
Fig. A.5 Map showing the location of the TAEs sampled in the field survey (Numbers indicate survey Phase) showing the typical extent of such modifications is given in Figs. A.6(a) and (b). Modifications were generally due to one of two possible factors: (a) the designated site was built on, in which case no such entity as 'ambient environment' existed at that point; (b) the site was inaccessible due to topography, building and street design or private ownership. In all cases the actual site surveyed was at the nearest accessible point with a similar environment.

These factors can have a significant bearing on the results of environmental surveys by effectively limiting the spatial comprehensiveness of the concept of the 'ambient environment' being observed. This argument did not apply so critically in the case of area appearance since, as section 7.3.2 of the main text makes clear, the evaluation was made on the visual condition of the whole 'location' area and this is not particularly constrained by physical accessibility or ownership. In the case of the ambient noise study however the 'point-receptor' nature of the measurement method meant that the proportion of the TAE land area that could actually be measured - and therefore for which the subsequent prediction models applied - was restricted to the accessible areas only. This issue applies to all ambient noise surveys and to other environmental surveys where the 'point-receptor' type of measurement is used (air pollution is another example). The issue is naturally increasingly important in proportion to the building density of areas; research by JURUE (1977) has shown that some 75% of city centre land area is covered either by buildings or roads, and is therefore inaccessible. Consequently the proportion of highly-urbanised land which actually has an 'ambient noise environment' to be measured and predicted is comparatively small, and the fact that as building density increases such land is increasingly of a 'kerbside' nature clearly has an important role in the observed increase in area-mean noise levels reported in the main text.

Fig. A.6 Example of the typical modification in sample site position



(a) Master overlay designation of sample sites.



(b) Actual array of sites observed.

A.5 FIELD SURVEY: COLLECTION OF DATA

Figs. A.7(a) and (b) show the two data sheets used in the recording of data collected during the field survey. The two data sheets were completed at every 'location'; sheet (a) records a wide range of data, while sheet (b) is designed specifically for ambient noise data.

On arrival at a location 'centroid' site by survey van , the normal procedure was for the surveyor to complete the noise survey and then conclude with the remaining data; this order was adopted because the tasks of classifying the 'location' in terms of the various urban fabric systems, and the evaluation of the area appearance, depended upon visual information obtained by the surveyor during his tour of the individual noise-measurement sites. The air pollution data were collected for the purposes of other research not discussed in the thesis. Wind direction was estimated from the motion of clouds, smoke, trees, wind felt on face, etc., with the aid of a simple compass. The Beaufort Scale windspeed was estimated using the 'description statement' technique and the statements given in Table A.1 (AIR MINISTRY 1962). Photographs were also taken which typified the area or illustrated features of interest; some of these are used to illustrate the 'TAE type monographs' in Appendix D. Figs. A.8 and A.9 show the survey van and noise survey equipment. The complete survey of a location took approximately an hour, and with the addition of the time taken to travel by survey van from one location to another, it was found that the complete survey of a sample TAE took some six to seven hours, thus fitting conveniently into the 'working weekday' period (0900-1730) defined in section 5.1.2 of the main text.

The measurement method for area appearance is described in detail in section 7.3.1 of the main text because it embraced substantive research issues. The ambient noise survey technique was a more commonplace procedure, being essentially similar to the many ambient noise surveys

Fig. A.7(a).Copy of First Data Sheet Used in the Survey

LOCATION IDENTITY

Area No.	
TAE Type	

Location Class No.	
Day/Time	

NON-ENVIRONMENTAL DATA

AREA TYPE OBSERVED	
TAE Type	
BS 4142	
WSL	
Buchanan	

METEOROLOGICAL DATA	
Wind speed	
Wind direction	
Vert Mixing	
Day temp	

ENVIRONMENTAL CONDITIONS

AIR POLLUTION					
	Initial	Final	I-F	Time	Concentration
SO_2					
SMOKE					
Identifiable sources					

AREA APPEARANCE (Ordinal scores)			
Building Decay		Dereliction	
Visual Intrusion		Aesthetic Quality	
Overall Area Appearance			
Comments			

PHOTOGRAPHS	
i.	ii.
iii.	iv.

Fig. A.7(b). Copy of the Second Data Sheet Used in the Survey

LOCATION IDENTITY

TAE Area No.	
Location Class/No.	

AMBIENT NOISE CONDITIONS

Site Class B1		
Noise Levels (dBA)	15 sec readings Time (a) (b)	Means
Upper		
Lower		
Primary Source	Secondary Source	
Comments		

Site Class B2		
Noise Levels (dBA)	15 sec readings Time (a) (b)	Means
Upper		
Lower		
Primary Source	Secondary Source	
Comments		

Site Class B3		
Noise levels (dBA)	15 sec readings Time(a) (b)	Means
Upper		
Lower		
Primary Source	Secondary Source	
Comments		

Site Class B4		
Noise Levels (dBA)	15 sec readings Time (a) (b)	Means
Upper		
Lower		
Primary Source	Secondary Source	
Comments		

Table A.1. Beaufort Scale Windspeed Measurement System.

(Source: AIR MINISTRY 1962)

Aston University

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Fig. A.8. Photograph showing the van used in the survey.

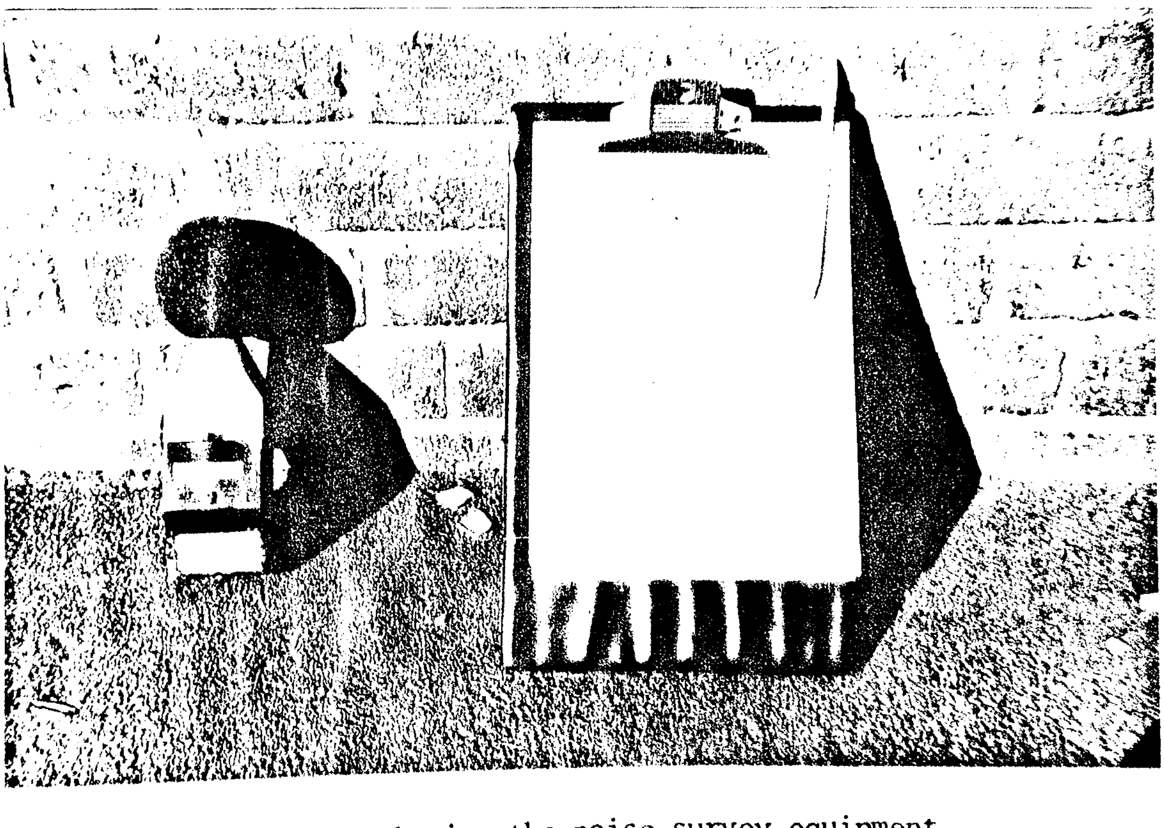


Fig. A.9. Photograph showing the noise survey equipment.

using hand-held sound level meters described in the main text (Chapter 5), and the details have therefore been reserved for this Appendix. At each survey site the noise conditions were measured by the UNL and LNL technique described in Section 5.3.1 in the main text using five-minute observation periods. Having toured the four sites in a given location the surveyor repeated the itinerary, thus achieving two observations of UNL and LNL at each site, separated on average by an interval of some 30 minutes. The average of these two observations was termed the 'site-mean' and was used to represent the UNL and LNL conditions of the site as described in section 5.2.1; the difference between the two observations was used to estimate the temporal variance of the noise conditions through a procedure discussed in Section 5.3.2 and Appendix B.

The 'lightweight' measurement technique meant that the surveyor needed to carry with him only a hand-held sound level meter and a clip-board, as was shown in Fig. A.9; the surveyor's normal position for taking measurements is shown in Fig. A.10. The instrumentation consisted of a single Bruel and Kjaer precision sound level meter type 2206, calibrated on a standard B + K 94.2 dBA, 1000Hz tone calibrator type 4230 before observing each location. After making such modifications to the position of the measurement site necessary as a result of the issues discussed in the previous section A.4, and avoiding reverberation and reflection phenomena by maintaining a distance of at least 1.5m from any walls or other vertical surfaces that might cause measurable sound reflection, observations were made using the procedure detailed in section 5.3.1 of the main text. Fig. A.10 shows the normal position taken up by the surveyor.

While conducting this survey, the surveyor encounters a number of operational difficulties. On occasions when the windspeed is high (Beaufort Force 6 or above) the microphone is prone to response from wind-induced vibration and noise from the foam wind-protector, and so

Fig. A.10 Photograph showing the normal position taken up by the surveyor while measuring noise levels.

observations were not made in these conditions. In quiet conditions (40 dBA and below) the surveyor can easily artificially disturb the noise level by coughing, sneezing, shuffling his feet or rustling the data sheets.

The surveyor is also at risk of perturbing the environment he is attempting to observe. In residential areas it is common to find that dogs are easily provoked by an intruder and may bark persistently throughout the surveyor's visit. In quiet areas, birds can also become disturbed by the surveyor's presence and their alarm-calls may raise noise levels over 10 dBA. Children too are easily excited once they have divined the surveyor's purpose, and frequently attempt to raise the ambient noise to an artificially high level by means of shouts, chanting and singing. For this reason it is vital for the surveyor to go about his business discreetly. In cases where the surveyor considered that he had perturbed the ambient noise level it was understood that the individual 'perturbed' 15-second noise readings should be deleted and the observation continued until ten un-perturbed readings were obtained.

This appendix has given an account of the technical details which support the empirical case study approach to testing the TAE methodology. The use and transformation of secondary source urban fabric data to give a map of the urban fabric of the WMMC in terms of TAEs has been described, and the survey method and data collection exercises resulting in data for the ambient noise and area appearance studies have also been detailed. Further details concerning analytical issues in the ambient noise and sulphur dioxide studies are given in the following two appendices.

APPENDIX B

TECHNICAL ISSUES RELATING TO THE AMBIENT NOISE STUDY

B.0 INTRODUCTION

This appendix gives the detailed technical information supporting the survey and analysis of ambient noise conditions as described in Chapter 5 of the main text. There are five sections; the first lists the urban fabric categories used in other area-based ambient noise studies, from which the TAE hypothesis was derived, while the second discusses the spatial and temporal sampling issues. The third section analyses the UNL/LNL indicators, comparing them with the percentiles L_{10} and L_{90} (for which they are approximations), and describing the method for estimating the L_{eq}. The following section gives the method for deriving the matrix of error variances due to spatial and temporal sampling errors, and the use of the matrix to provide the data for correcting the B and W components of the F-test. Finally a section describes the background to the development of the windspeed-noise model.

B.1 URBAN FABRIC CATEGORIES IN CONTEMPORARY AREA-BASED AMBIENT NOISE STUDIES

In the main text both Chapters 4.3 and 5.1 have made reference to the established area-based ambient noise prediction methods upon which the hypotheses for the TAE methodology were in part based. Table B.1 lists four of the urban fabric classification systems used in contemporary examples of such methods in Tokyo (TOKYO METROPOLITAN GOVERNMENT 1977), Vancouver (PRICE 1972), the UK (BRITISH STANDARDS INSTITUTION 1967, 1975, GILFORD and NORRIS 1973, ATTENBOROUGH et al 1976), and Calcutta (PRAHBU and CHAKRABORTY 1978). The similarity between these classification systems is evident, as is their influence on the classification of TAE types defined in the research; this and the similarity in actual noise levels within similar urban fabric area types is illustrated in Table 5.11 of Chapter 5.6.1.

Table B.1 Urban Fabric Classification Systems Used in Contemporary Ambient Noise Surveys

Study Area and Researchers			
Tokyo (T.M.G. 1977)	Vancouver (Price 1972)	UK (BSI 1967, Attenborough et al 1976)	Calcutta (Prabhu and Chakraborty 1978)
Residential A Residential B Residential Quasi-commercial Commercial Quasi-industrial Industrial Exclusively industrial	Rural Residential Commercial Industrial	Rural Suburban (little traffic) Urban residential Urban residential, some industry Intermediate residential and industrial Predominantly industrial	Residential Institutional Industrial Commercial Commercial/public (each divided into 3 urban density categories)

The main text (e.g. Chapter 4.2.3 and elsewhere) refers to the fact that the urban fabric nature of areas cannot be properly considered in the absence of guidelines on the size of the area unit to be classified. Furthermore a standardised and repeatable classification method requires quantitative criteria to be defined detailing the composition of each category. Neither of these conditions is explicitly treated in the four classification systems shown, a fact which makes comparison of the relevant noise levels with the TAE type noise levels problematical, and highlights in contrast the relatively rigourous approach adopted in the application of the TAE classification method.

B.2 SAMPLING PERIOD AND SAMPLING DENSITY

(a) Sampling period

Chapters 5.1 and 5.3 of the main text refer to the fact that the required sampling period for a given ambient noise survey depends upon the temporal variability of the noise levels being observed and the required accuracy of the resulting measurements. It was noted in Section 5.1.2 that temporal variability is commonly considered in two stages; firstly the variability <u>within</u> a sampling period results in a statistical distribution of noise levels which may be represented by statistical parameters e.g. the L_{10}, L_{eq} etc; secondly the variability of these parameters over some longer-term 'climatic' period results in the notion that sample parameters are estimates of the total 'climatic' population parameters with an accuracy which is assessed through their standard errors.

Fig. B.1 illustrates the short-term variation of noise levels in a typical urban environment over a sample period of 8 minutes. Further

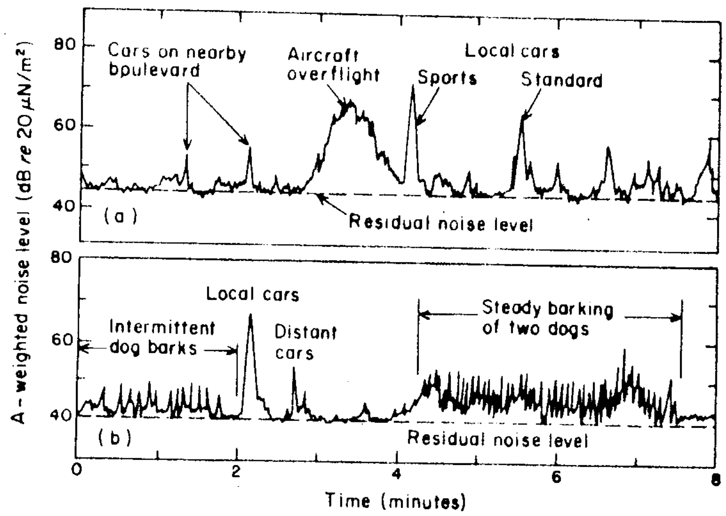
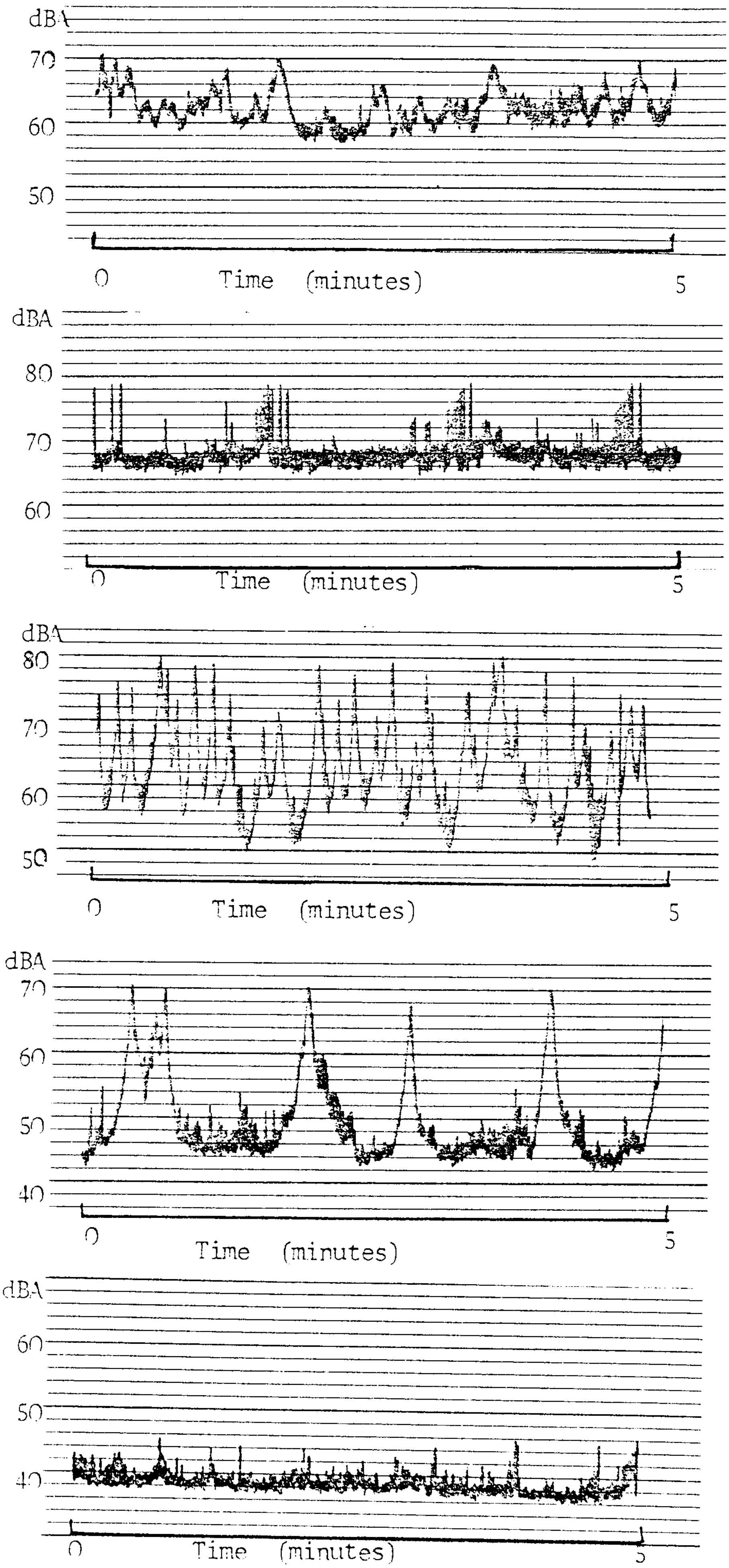


Fig. B.1 Example of typical short-term ambient noise variations and sources (Source: ELDRED 1975).

examples taken from a range of urban environments are given in Fig. B.2; they were obtained from sample sites observed in the research and cover a five-minute sample period. Trace (a) was obtained in Langley, Sandwell, with the microphone situated on wasteland some 20m from a moderately-trafficked road beyond which at a distance of some 100m was a large industrial site. Trace (b) was also obtained in Langley, at a site adjacent to a foundry; intermittent impact noises are imposed over a steady industrial background coupled with passing lorries. The remaining

Fig.B.2 Five-minute noise level 'traces' obtained in different types of noise climate.



(a) Industry and traffic noise at 30m from the roadside.

(b) Industrial noise: steady background and repeated impulses.

(c) Traffic noise at a busy kerbside.

(d) Quiet suburban road with occasional passing cars.

(e) Quiet suburban back garden.

three traces were recorded at sites of a residential character, in Boldmere, Birmingham. Trace (c) was observed at the kerbside of a busy trunk road passing through an otherwise quiet suburban area; traffic is seen to be passing continuously giving a highly variable noise environment. Trace (d) was obtained at a site 5m from a quiet suburban road; a steady background level mostly due to distant traffic is interrupted by occasional passing cars. Finally, trace(e) was recorded in an access path behind the back gardens of a quiet suburban cul-de-sac; only a few bird calls and distant dog barks interrupt the steady, low-level background noise.

The continuous traces illustrate qualitatively the validity of the assumption implicit in the measurement method used in the research, that indicators (the highest and lowest noise levels) observed over 15-sec intervals followed by 15-sec pauses will generally be independent samples; this is evident from the fact that the traces obtained over a cross-section of types of noise environment consist of successive noise 'events' lasting for the most part considerably less than 30 seconds, and also from the fact that trends in the general level of noise are not evident over the 5-minute sample period. The five-minute observed values of UNL and LNL (determined according to the method described in Chapter 5.3.1) are therefore statistically valid measures of the noise conditions obtaining within the sample period.

As stated, the error of estimate in using five-minute samples to represent long-term 'climatic' parameters depends upon the amount of variation that occurs over periods longer than the sample period. The assumption in the use of the 'standard error of estimate' as a measure of sample accuracy is that there exists a long-term 'climatic' population of indicator levels, consisting of a (theoretically infinite) set of five-minute sample indicator values independently and randomly distributed within the 'climatic' period. The standard deviation of this population is thus equivalent to the standard error of estimate in using the value of a single five-minute sample to represent the population ('climatic period') mean. This conceptual approach therefore implies that, in accordance with normal statistical theory, the sampling error of estimate is systematically reduced as the sampling period is increased. In fact, if the assumption of random, independent five-minute sample indicator values is valid, a doubling of sample time would reduce the standard error of estimate by a factor of $\sqrt{2}$.

The research used a specially-conducted survey (termed 'S'-survey) to test this proposition empirically and to quantify the error of estimate in the sample indicator values measured at any given site. Noise levels were measured for an hour at the five survey sites already described in section B.1, resulting in twelve five-minute samples of UNL and LNL at each site. Applying the Bessel correction factor for small samples (as described for example in BLALOCK 1964) a 'best estimate' of the standard deviation σ_o of the (theoretically infinite) population of five-minute samples was obtained at each site, and the results are given in Table B.2 together with a 'pooled' figure representing the average variance for the five

<u>Table B.2</u> <u>Best Estimates of Sample Standard Deviations σ_o and σ_s (dBA)</u>

Standard deviation	Sample Site Values (dBA)					Pooled values (dBA)	$\frac{\sigma_o}{\sigma_s}$
	S_1	S_2	S_3	S_4	S_5		
σ_o (UNL)	1.02	1.61	3.16	1.76	1.57	1.96	2.04
σ_s "	0.83	0.69	2.29	1.25	1.17	1.37	
σ_o (LNL)	0.54	0.76	0.71	1.14	0.50	0.76	2.31
σ_s "	0.36	0.31	0.32	0.89	0.37	0.50	

sites. Now, it will be remembered that the research case study used measurements of UNL and LNL at each observation site, which consisted of the mean of <u>two</u> five-minute sample values, separated, on average, by a period of 30 minutes. Using this same technique at the five 'S'-sites, six independent means of paired five-minute samples separated by 30 minutes were obtained, and these were similarly Bessel-corrected and pooled to give an appraisal of the standard deviation of the site means, σ_s, as also shown in Table B.2. If, as assumed, the paired five-minute samples are statistically independent then the ratio $\frac{\sigma_o^2}{\sigma_s^2}$ should be equal to 2; Table B.2 shows that this is in fact approximately the case and therefore the assumption that the paired five-minute samples which go to make the 'site-mean' data in the case study were random and independent appears to be valid. Consequently the values of σ_s for UNL and LNL correspond to the standard errors of estimate for the site-mean UNL and LNL, as determined by the 'S'-survey data. Section B.4 discusses a further method for estimating σ_s from a larger sample of data, but the resulting values are found to be almost exactly identical to thos given in Table B.2.

The results of the rigourous statistical approach used in this research are difficult to compare with the more arbitrary methods for assessing the accuracy of short-term ambient noise sampling used in other studies. Tables B.3(a) and (b) show the results of two studies which

Table B.3(a) Differences Between Highest and Lowest Sample Values for Various Sample Deviations

Distributive Statistics		Difference Values (dBA) for Various Sample Durations (mins)			Full hourly indicator value (dBA)
		5	10	20	
Rectangular	L_{10}	3	2	1	74
distribution	L_{90}	12	11	4	58
Skewed	L_{10}	12	10	4	52
distribution	L_{90}	6	6	1	43

Source: Safeer et al 1972.

assessed the sampling error not by the standard error but by the value of the difference between the highest and lowest sample values for samples of a given duration taken continuously over an hour. The reduction of error with increase in sampling time is evident, but the method does not statistically test sample independence as was done through the 'S'-survey.

Table B.3(b) Differences Between Highest and Lowest Sample Values for Various Sample Durations

Distributive Statistics	Difference Values (dBA) for Various Sample Durations (mins) 10	20	30	Full hourly indicator value
Rectangular L_{10}	2.1	0.7	0.5	67.9
distribution L_{90}	1.7	0.5	0.3	56.6
Skewed L_{10}	9.4	5.7	3.4	56.1
distribution L_{90}	0.9	0.2	0.4	42.2

Source: Schulz 1972, using 1-hr total sample period.

In general the results support the 'S'-survey findings of higher sampling errors in L_{10} (UNL) than in L_{90} (LNL).

The evidence supports the proposition that a valid estimate of long-term mean indicator values may be obtained by five-minute samples, and that by estimating the mean from the mean of two such samples separated by 30 minutes (the 'site-mean'), the standard error may be reduced to comparatively low levels. The proposition that the site-mean may be used as a statistical estimate of a long-term population mean does however involve the assumption that no significant long-term trends exist over the period covered by the population of noise indicator levels - this was seen in Chapters 3.1 and 5.1 to be essentially what was meant by a 'climatic' period and population. Clearly, ambient noise levels vary significantly over the 24-hour period in accordance with man's basic behavioural patterns, as illustrated by the typical urban daily noise cycle shown in Fig. B.3. Table B.4 (due to ATTENBOROUGH et al 1976) presents a similar account, and highlights the fact that weekends are generally quieter than weekdays. The delimitation of a 'working weekday' climatic period (0900-1730, Monday - Friday) for the basis of the research identified a period within which contemporary studies have indicated that ambient noise levels are broadly trend-free, and for which it

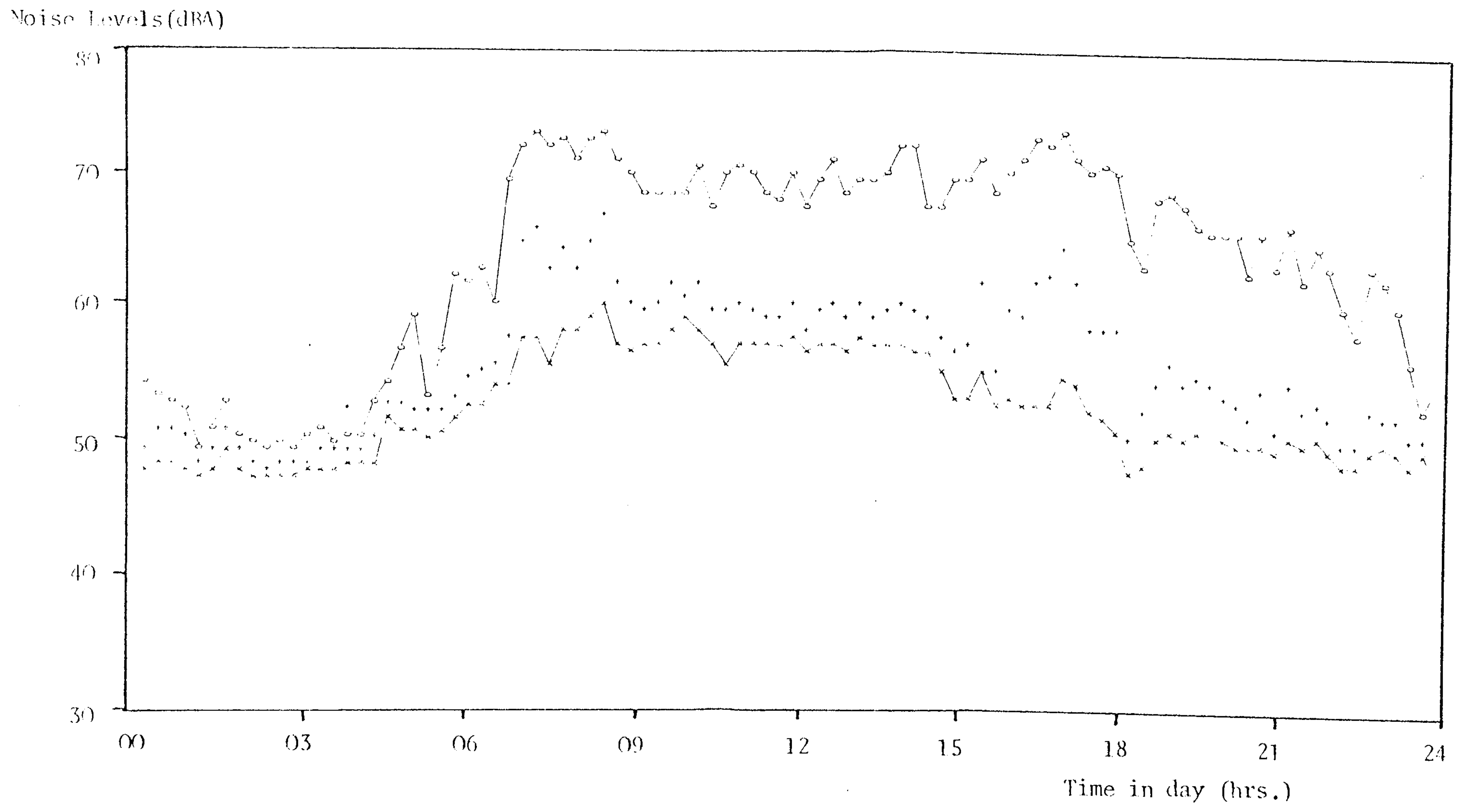


Fig.B.3 Example of 24-hr Variation in Ambient Noise Levels (Source: Birmingham Environmental Protection Unit)

Table B.4 Mean Noise Level 'Corrections' Relative to Weekday, 0900-1100 period (Source: Attenborough et al 1976)

Time Period	Mean Noise Level Correction (dBA)
0900 - 1100 weekdays	0.0
1200 - 1400 "	+0.16
1600 - 1800 "	+0.45
2000 - 2200 "	-4.07
2400 - 0700 "	-10.36
1400 - 1600 Sundays	-2.48

appeared therefore reasonable to assume that site-mean samples were random, unbiased estimates of the 'climatic' population mean. Subsequently the research discovered that significant between-day variance occurred, principally in association with variation in windspeeds, and considerable analytical effort was expended in normalising the data to a standard, 'lightwind' condition and revising the error of estimate of site-means (and therefore, of TAE area-means) in representing the long-term working-weekday 'climatic' mean; this is described in Chapter 5.3 and sections B.4 and B.5.

(b) Sampling density

The issue of sampling density is considered in some detail in the main text, Chapter 5.3.1. Originally the stratified spatial sampling system illustrated in Fig. 5.3 was designed to allow the two sampling densities (sites for location unit, and locations for TAE unit) to be compared. However, mainly due to time and resource limitations, it was not possible to achieve this in the research. In any event, a proper investigation of optimal sampling density would require a wider range of densities to be compared, and the operational issues affecting the required data accuracy to be tested (see Chapters 3.1, 3.4 and Chapter 9.1). Thus the research is limited to comparing the overall

TAE sampling density with densities (and methods for site selection) used in other contemporary studies; this is achieved in Table B.5 in which for comparative purposes the site densities are standardised in terms of 'sites per sq. mile'. From the table it is evident that the research adopted a high sampling density than any of the other studies; it is argued in chapters 4.4 and 9.2 of the main text that one of the advantages of the 'area-based spatial prediction model' mapping method is that it reduces field survey work to the examination of only a small number of sample frame areas, for which very high spatial sampling densities therefore become feasible, resulting in increased accuracy in the estimates of the area-mean indicator values.

Table B.5 Comparison of Spatial Sampling Factors in Contemporary Ambient Noise Surveys

Researchers	Study Area	Sampling density (sites pr.sq.mile)	Method for site location
Senko and Kirshnan (1971)	New York	25	Random within 1 sq.mile 'homogeneous' units.
Price (1972)	Vancouver	18 (average)	Arbitrary, from 0.1 mile grid co-ordinates
Gilford and Norris (1973)	West Midlands (UK)	0.1 (1 per sq.km)	Random, on 3km grid
Attenborough et al (1976)	UK	Not known	Arbitrary, decided by surveyors all over UK
Benedetto and Spagnolo (1977)	Turin	2.2 + (1 per sq. km +)	Random on 1 km grid plus deterministic sites at half the density
Tokyo Metropolitan Government	Tokyo	2	Arbitrary, one roadside, one back garden per sq. km.
Prabhu and Chakraborty (1978)	Calcutta	0.75 (average)	Random selection from 0.5 km grid co-ordinates
Pocock (1979)	West Midlands (UK)	33	Random, stratified sample within 1.25 X 1.25 km 'homogeneous' units

B.3 ANALYSIS OF INDICATOR METHODS

The 'S'-survey, which has already been discussed in this appendix, was conducted with the prime intention of investigating the extent to which the indicators UNL and LNL reflected the values of the percentile distributional indicators L_{10} and L_{90}. Chapter 5.3.1 of the main text has referred to the conclusions of other researchers (e.g. MOCHIZUKI 1967) that UNL and LNL may be used as estimates of L_{10} and L_{90}, but no assessment of the accuracy of the approximations was available. The 'S'-survey results were therefore used to test the accuracy of using UNL and LNL as a percentile approximation method.

At each of the five sites (described in section B.1) values of five-minute samples of UNL and LNL were obtained continuously over an hour. Simultaneously a tape recording of the noise was made by feeding an electronic output from the hand-held sound level meter into a Uher 4200 IC reel-to-reel tape recorder. In the laboratory a series of five-minute measurements of L_{10} and L_{90} corresponding to the contemporaneous measurements of UNL and LNL was obtained by passing the tape recorder output through a standard Bruel and Kjaer Statistical Analyser in a sequence of five-minute sample periods. Thus at each site, twelve independent pairs of indicator values for UNL and L_{10}, and LNL and L_{90}, could be compared. The comparison method involved an analysis of the distribution of the numerical differences between the paired indicators, the results of which are presented in Table B.6. In the case of both pairs of indicators, sixty independent samples of the difference between the paired values were available across the sample frame of five types of noise environment encompassing the range of noise levels and short term statistical variability. The mean differences ($\overline{UNL - L_{10}}$, $\overline{LNL - L_{90}}$) and the standard deviation of the differences were calculated, and the results are shown in Table B.6 together with the mean indicator values and the mean differ-

Table B.6 Mean Differences Between Percentile Indices and the UNL/LNL Values, and Standard Deviation of the Differences (dBA)

Indices	Sample Sites S_1	S_2	S_3	S_4	S_5	Mean Differences	Standard Deviation of Differences
UNL	64.2	73.3	59.3	73.8	42.2		
L_{10}	64.8	73.2	60.2	72.2	43.0		
UNL-L_{10}	+0.6	+0.1	-0.9	+1.6	-0.8	-0.2	1.06
LNL	58.0	66.5	43.9	51.9	38.2		
L_{90}	58.1	66.9	44.0	52.5	37.9		
LNL-L_{90}	-0.1	-0.4	-0.1	-0.6	+0.3	-0.2	0.34

ences at each of the five sample sites. The fact that both indicator pairs show the same mean differences (-0.2 dBA) could imply that the mean difference itself is simply due to a calibration bias in the statistical analyser. From the standard deviation of the differences one may say that there is a 95% confidence that the L_{10} will lie within $\pm$2.1 dBA of the observed UNL, and that the L_{90} will lie within $\pm$ 0.7 dBA of the observed LNL. Using the students t-test the observed mean difference between the paired indicators was not found to be statistically significant at the 1% level, and consequently it is statistically valid to consider the UNL to be an estimate of the L_{10}, and the LNL an estimate of the L_{90}, assuming an accuracy of estimate as given above.

Chapter 5 of the main text discusses the use of L_{eq} as a single overall indicator to represent ambient noise conditions. While not measured directly in the research (due to instrumentational difficulties which have been overcome by recent technological advances as described in Chapter 5.3.1) it was found to be possible to use a simple approximation technique based on the values of L_{10} and L_{90}. One such technique is reported in NOISE ADVISORY COUNCIL (1978) and is given by the relation:

$$L_{eq} = \frac{(L_{10} + L_{90})}{2} + \frac{(L_{10} - L_{90})^2}{57} \qquad B.1$$

This is however a highly simplified approximation and it was decided to use a more detailed method based upon the precise technique whereby L_{eq} is calculated by such instruments as statistical analysers. As referenced in the main text, this relation is given by:

$$L_{eq} = 10 \log_{10} \left[\frac{1}{100} \sum_{i=1}^{N} \left(f_i \cdot 10^{L_i/10} \right) \right] \qquad B.2$$

where f_i = relative frequency of noise distribution interval i (%).

L_i = mean noise level of noise interval i.

N = total number of intervals into which the distribution is divided.

(CUNNIFF 1977)

This relation was approximated by assuming a normal distribution of noise levels and dividing the distribution into four intervals. Assuming normality, the observed value (UNL-LNL) may be used to calculate the standard deviation of the distribution, σ, since if the percentile approximation is made, then from tables,

$$UNL - LNL = 2 \times 1.29\,\sigma$$

$$\sigma = \frac{UNL - LNL}{2.58} \qquad B.3$$

Dividing the distribution into intervals of σ up to $\pm 2\sigma$ (giving four intervals), using standard tables and approximating the mean noise level of each interval to the mid-point of the range covered, equation B.2 approximates to:

$$L_{eq} = 10\log_{10} \frac{1}{100} \quad 16.10^{L_1/10} + 34.10^{L_2/10} + 34.10^{L_3/10} + 16.10^{L_4/10} \qquad B.4$$

where $L_1 = \frac{UNL - LNL}{2} - \frac{3\sigma}{2}$

$L_2 = \frac{UNL - LNL}{2} - \frac{\sigma}{2}$

$L_3 = \frac{UNL - LNL}{2} + \frac{\sigma}{2}$ $\quad L_4 = \frac{UNL - LNL}{2} + \frac{3\sigma}{2}$

and σ is given by equation B.3

Like the other simpler approximation methods the technique is limited by its assumption of normality in short-term noise level distributions. It was not possible to test the additional errors resulting from the possible invalidity of this assumption because no method for assessing the departures from normality, for instance through skew, was available.

B.4 DEVELOPMENT AND USE OF THE SAMPLING ERROR MATRIX

Section 5.3.2 of the main text discussed the development of a 'sampling error matrix', the matrix is repeated in Table B.7. The application of the matrix to the correction of the data used in the hypothesis test, and to the determination of the error of estimate of the TAE prediction model, is discussed in sections 5.2.2 and 5.2.3. It was stated that the extensive analysis of the various sources of sampling error gives a uniquely comprehensive and detailed evaluation of the nature of the sampling issue, which of course faces all ambient noise surveys. This section describes the methods through which the matrix was quantified.

The main text details the general rationale of the approach, involving the determination of individual component sources of error variance, from which the error variances of given types of sample (e.g. daily TAE area-means, long-term windspeed-normalised TAE type means, etc.) were calculated by aggregating all the relevant component variances according to Equn.5.1, using the component elements i,j as defined in the accompanying main text.

The values for $C_{1,0}$ and $C_{0,2}$ were calculated directly from the Phase 1 survey data (N.B. $C_{0,1}$ was noted to be zero because data were available for all 20 sample sites in each TAE). Values were calculated for each sample TAE, and were then pooled to give an overall figure for the matrix. From the description of the measurement technique it will be evident that in each sample TAE, 40 five-minute UNL and LNL measurements (or twenty UNL and LNL site-means) were available, and that the variance of this sample contains both within-day temporal variance $C^2_{1,0}$ and within-TAE spatial variance $C^2_{0,2}$. The procedure for isolating and quantifying these components involved the use of the observed difference between the two five-minute samples made at each site; clearly there are 20 samples of such observed differences in each TAE, from which the standard error of the differences, σ_d, may be calculated. Since the two five-minute samples have been shown to be independent, the standard deviation of single five-minute measurements, σ_o, is given by $\frac{\sigma_d}{\sqrt{2}}$ and therefore the standard deviation of the site-mean (the mean of two independent five-minute measurements), σ_s, is given by $\frac{\sigma_d}{2}$. Thus a value of σ_s for each sample TAE could be observed, and this could be translated into a value for $\sigma_{1,1}$, the standard deviation of the observed area-mean, since the area-mean consisted of twenty independent site-means and therefore

$$\sigma_{1,1} = \frac{\sigma_s}{\sqrt{20}} = \frac{\sigma_d}{2\sqrt{20}} \qquad \text{B.5}$$

Thus, values of $\sigma_{1,1}$ for the UNL and LNL of each sample TAE could be calculated from the observed values of σ_d. The results obtained in this way from the Phase 1 data are shown in Table 5.4 of the main text, and these were pooled[1] to give the overall value of $\sigma_{1,1}$ used in the sampling errors matrix (Table 5.3). Since $C_{0,1} = 0$ then $C_{1,0}$ was simply equal to

1. The pooled standard deviation was achieved by averaging the variances.

Table B.7 Matrix of Temporal and Spatial Variation in Noise Levels, Showing Component (C) and Standard Error (σ) elements. (dBA; Pooled Data for all TAEs)

SPATIAL VARIATION \ TEMPORAL VARIATION		Within-day i=1	Between-day (wind-normalised) i=2	Between-day (Not normalised) i=3
		$C_{1,0}$ 0.30 0.18	$C_{2,0}$ 0.48 0.98	$C_{3,0}$ 0.89 1.95
Sample sites, Sample TAE j = 1	$C_{0,1}$ 0.00 0.00	$\sigma_{1,1}$ 0.30 0.18	$\sigma_{2,1}$ 0.57 1.00	$\sigma_{3,1}$ 1.06 2.19
All sites within sample TAE j = 2	$C_{0,2}^{*}$ 1.55 1.17	$\sigma_{1,2}$ 1.57 1.18	$\sigma_{2,2}^{*}$ 1.67 1.55	$\sigma_{2,2}^{*}$ 1.99 2.68
All sites, all TAEs (of same type) j = 3	$C_{0,3}^{*}$ 0.53 0.41	$\sigma_{1,3}^{*}$ 1.68 1.25	$\sigma_{2,3}$ 1.76 1.59	$\sigma_{3,3}^{*}$ 2.06 2.71

* Values estimated assuming r.m.s. addition of variances

$\sigma_{1,1}$. It is interesting to note that the pooled values of $\sigma_{1,1}$ were almost identical to the values already estimated from the 'S'-survey data in section B.2, and given in Table B.2. The method described above obtains $\sigma_{1,1}$ values of 0.30 and 0.18 dBA for UNL and LNL respectively; from the values of σ, calculated in Table B.2, the equivalent values of $\sigma_{1,1}$ are 0.32 dBA and 0.11 dBA.

It will be noted that the analysis of the within-day sampling error made no allowance for instrumental errors; this was because instrumental errors were not considered to be significant. This conclusion was reached by assuming an instrumental standard error in the precision-grade sound level meters of 0.5 dBA, and making the subjective estimate that the surveyor's visual recording accuracy was such that in the most variable noise environments (e.g. a busy roadside in an otherwise quiet area such as survey site (c) in section B.1), he was likely to perceive a level within ±2dBA of the actual level recorded by the meter. On this somewhat qualitative appraisal of the two components of instrumental error it was considered that a standard error of 1dBA for each 5-minute record of UNL and LNL was representative. Thus with ten records of UNL and LNL for each five-minute measurement, the standard instrumental error in a five-minute measurement was $\frac{1}{\sqrt{10}} = 0.32$dBA. On this basis the site-mean (two measurements) and area-mean (40 measurements) would have instrumental standard error components of 0.22 dBA and 0.05 dBA respectively. The area-mean error values are clearly insignificant when compared with the values in the error matrix, Table 5.3.

Having determined the value of $C^2_{1,0}$ it becomes possible to isolate this temporal variance and subtract it from the observed variance of the twenty site-means for each sample TAE, $\sigma^2_{1,2}$, to leave the component of variance $C^2_{0,2}$ due to spatial variation in noise levels within the TAE. Table 5.5 in the main text shows the results of performing this for each sample TAE in the Phase 1 survey, and the pooled values of these spatial variances appear in the sampling error matrix, Table 5.3.

The calculated value of the within-day temporal variance $C^2_{1,0}$ in area-means was based on the observed differences in five-minute measurements separated by a 30-minute interval. As a method for estimating the variance of noise levels within a single working weekday it is valid only for as long as no statistically significant trends occur within that period over intervals in excess of 30 minutes. This assumption was not tested empirically in the research, and in order to substantiate it, it was necessary to rely upon the evidence (given here in Table B.4) of ATTENBOROUGH et al (1976), and other qualitative evidence such as that given in Fig. B.3. Now if the same assumption could be extended beyond a single given working weekday such that no statistically significant trends occurred between days, then $C^2_{1,0}$ would be a valid estimate of the error variance in using the observed area-mean to estimate the long-term, 'climatic' population area-mean. The research found however that on a substantial number of occasions, significant between-day variations in area-mean noise levels did in fact occur, with components $C^2_{3,0}$ and $C^2_{2,0}$ due to windspeed variations and other unspecified factors respectively.

The Phase 3 data, comprising seven return visits to TAEs already surveyed in Phases 1 and 2, together with the data obtained on the seven original occasions, were used to test for significant between-day variation and to quantify its two possible component elements. The test for significant between-day variation was made using the student's t-test at the site mean, location-mean and area-mean levels for each of the seven sample TAEs. For the appropriate degrees of freedom the method was applied as described by BLALOCK (1964), with the value of t being given by the ratio of the observed difference between the relevant means (site, location or area) observed on the two occasions, to the pooled estimate of the standard error of difference obtained from the observed values of σ_d (Bessel-corrected in the cases of location and site means where the pooled σ_d values were based on two and eight samples respectively). Table B.8 shows the results of applying the t-test to the 140 sites, 35 locations and seven areas (TAEs) respectively, giving the number (and percentage) of occasions upon which the t-test showed that significant between-day variation had occurred over the period separating the two surveys. It is seen that, in passing from UNL to LNL and from site-means to area-means,

Table B.8 Frequency of Occasions Upon Which Significant Between-Day Variance was Observed, Before Normalisation for Windspeed

Data	'Site-means' Number % ( )	'Location-means' Number % ( )	'Area-means' Number % ( )
UNL observed	21 (15)	13 (37)	4 (57)
LNL observed	58 (41)	27 (77)	7 (100)

there is a steady increase in the frequency with which statistically significant between-day differences occur. This implies that between-day variations in noise levels occur most prominently in the lower, 'background' noise levels rather than in the 'peak' noise levels, and are large-scale phenomena affecting TAE zones as a whole rather than individual sites.

As stated, the effect of a significant between-day variance is to increase the standard error in using an observed area-mean to represent the long-term 'climatic' population mean, from the value of $C_{1,0}$ to a higher figure. If however an amount of the between-day variance may be ascribed to the effect of independent parameters then a prediction model may be developed in terms of such parameters which may allow the data to be normalised to some standard independent parameter condition, thus removing a certain proportion of the extra error of estimate. This is precisely what was achieved in the research, by explaining a high proportion of the between-day variance in terms of the variation in windspeeds, as detailed in the following section B.5. As a result there are two notions of the long-term climatic sampling error: one which applies to a windspeed-normalised population and one which also includes the between-day variations due to wind. Clearly the latter is a straightforward estimate of the error in using an area-mean observed on any one day to represent the long-term climatic mean, while the former estimates the error in using an area-mean which has been normalised through a correction applied by a 'windspeed-noise prediction model', to represent the long-term climatic mean.

The method for calculating the components of variance due to windspeed ($C^2_{3,0}$) and the remaining unspecified factors ($C^2_{2,0}$), involved analysis of the observed differences between the indicator means recorded on the two separate survey occasions. The statistical distribution of these differences for the site, location and area means are shown in Figs. B.4(a) and (b) for UNL and LNL respectively. The figures compare for each set of means the differences in observed means before and after normalisation for windspeed, and the reduction in the variance of the between-day differences when normalisation is applied is evident, particularly in the case of LNL.[1] The statistical analysis of these distributions proceeded by obtaining the standard deviation of the differences of each, and dividing by $\sqrt{2}$ to achieve the standard deviation of the means themselves. This data is presented in Table B.9 as the standard errors of estimate in using the relevant observed means to represent their

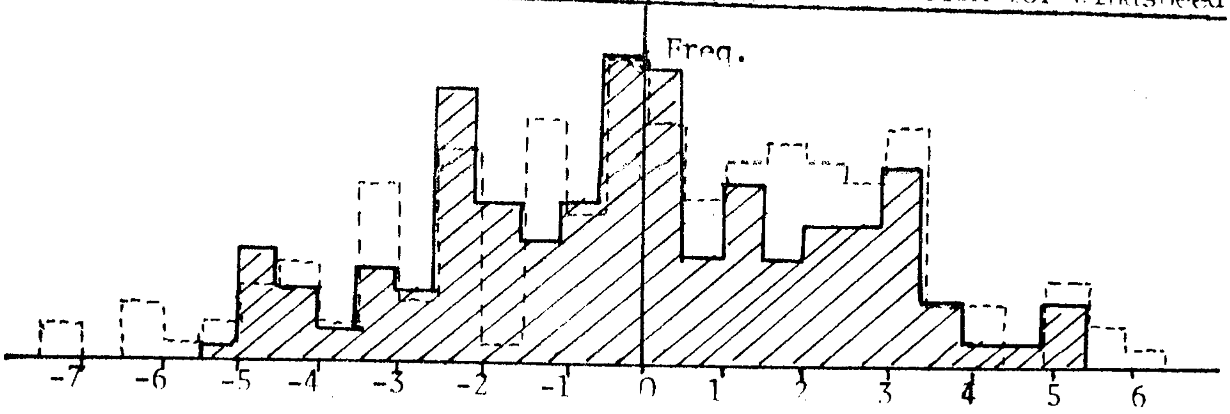
Table B.9 Standard Errors of Estimate in Using Sample Means to Represent Long-Term Means, Normalised and Non-Normalised for Windspeed (dBA)

Data Set	'Site-means'	'Location-means'	'Area-means'
UNL (Not Normalised)	2.19	1.41	1.06
LNL "	2.69	2.33	2.19
UNL (Normalised)	1.84	1.00	0.57
LNL "	1.84	1.41	1.00

appropriate long-term climatic means; thus at the area-mean level the figures represent the values of $\sigma_{3,1}$ and $\sigma_{2,1}$ respectively in the sampling errors matrix, Table 5.3. From these, $C^2_{3,0}$ may be determined directly by subtracting $\sigma_{2,1}{}^2$ from $\sigma_{3,1}{}^2$, and $C^2_{2,0}$ by subtracting $C^2_{1,0}$

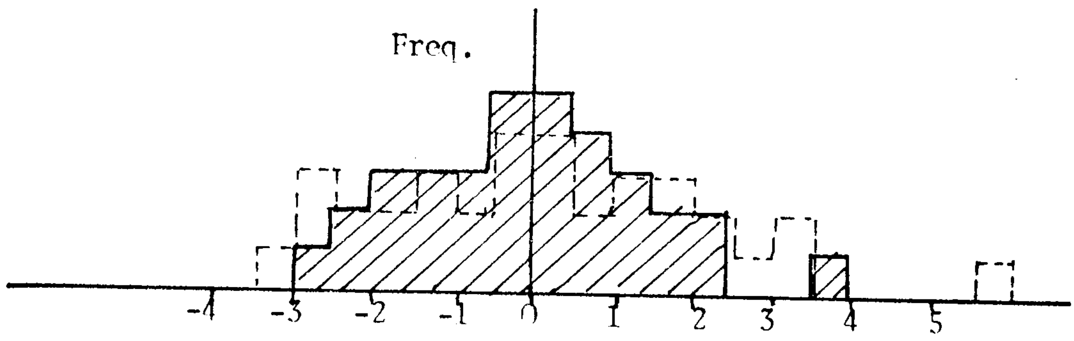
1. The following section substantiates the intuitively reasonable conclusion that windspeed has its strongest effect on the lower noise levels.

Fig. B.4(a) Histogram of differences in UNL values observed on two separate occasions, before (---) and after (—)normalisation for windspeed.



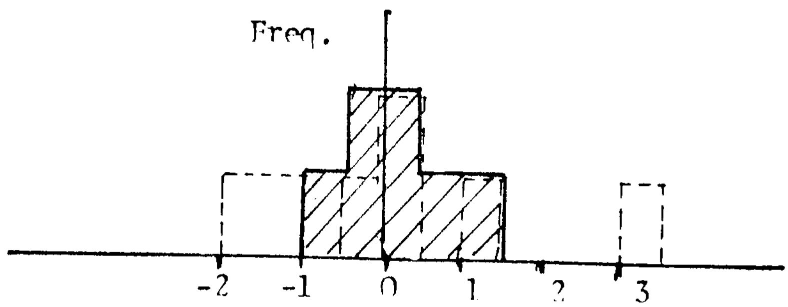
(a) For observed site-means

Change in UNL(dBA)



(b) For observed location-means

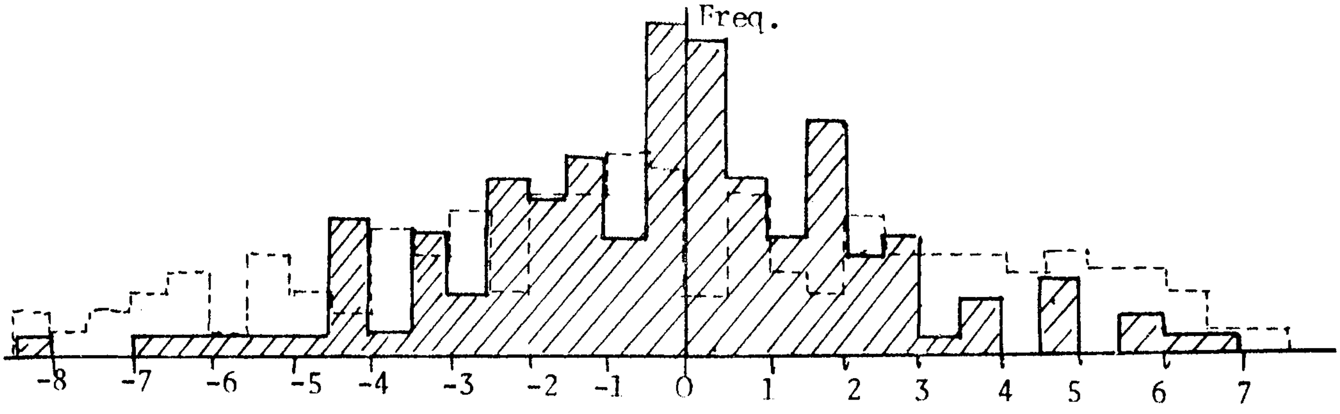
Change in UNL (dBA)



(c) For observed area-means

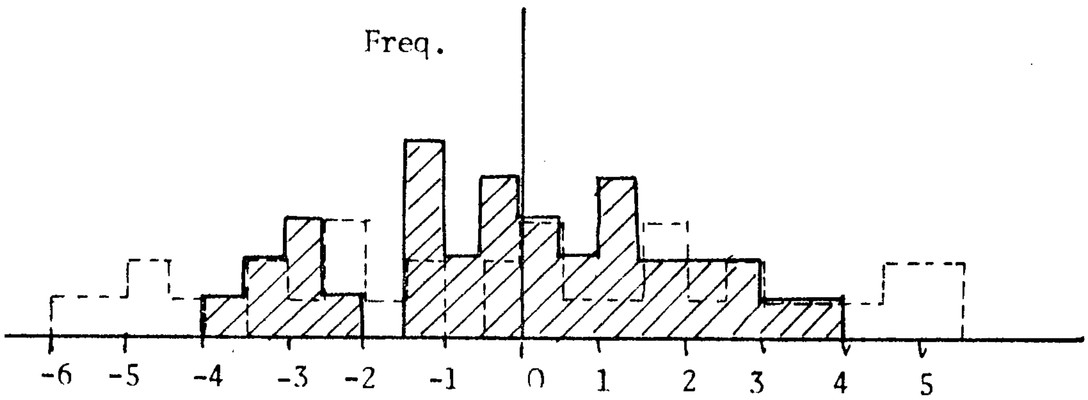
Change in UNL (dBA)

Fig. B. 4(b) Histogram of differences in LNL values observed on two occasions, before(---) and after(——) normalisation for windspeed.



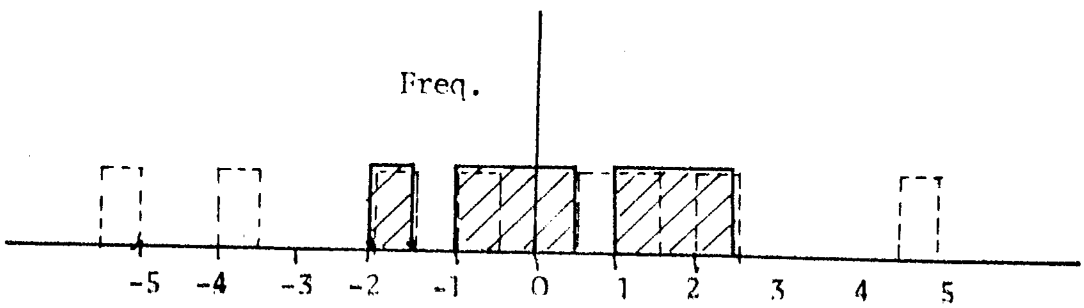
(a) For observed site-means

Change in LNL (dBA)



(b) For observed location-means

Change in LNL (dBA)



(c) For observed area-means

Change in LNL (dBA)

(already calculated) from $\sigma^2_{2,1}$.

The effect of normalising all noise measurement to a standard 'light wind' condition is to reduce the number of occasions when significant between-day variances occur. The data from which Table B.8 was derived were normalised and the t-test was applied as before, and Table B.10 shows

Table B.10 Frequency of Occasions Upon Which Significant Between-Day Variance was Observed, Before and After Normalisation for Windspeed

Data	'Site-means' Number %( )	'Location-means' Number %( )	'Area-means' Number %( )
UNL observed	21 (15)	13 (37)	4 (57)
UNL Normalised	18 (13)	11 (31)	2 (29)
LNL Observed	58 (41)	27 (77)	7 (100)
LNL Normalised	31 (22)	20 (57)	6 (86)

the reduction in the incidence of statistically significant between-day variance. The most substantial reductions are made in relation to the LNL means, but it is clear that significant between-day variance is still commonplace. The factors causing this variance are undetermined, but over the 2-6 month period covered by the data they might be expected to include variations in daily traffic density and composition, holiday periods for schools and industry, short-period road works and construction activities, and permanent changes in built form and traffic management.

The remaining sampling error element is $C^2_{0,3}$, the component of variance existing between TAEs of the same type. This was estimated from the Phase 2 survey data which involved area-means being observed at eleven TAEs falling into seven of the TAE types surveyed in Phase 1. The Phase 2 area-mean data are presented in Table B.9, showing the wind-normalised values for the area-means and the differences between these and the normalised area-mean values for the relevant Phase/TAE of the same type. The standard deviation of the differences was calculated (Bessel-corrected because only eleven samples were available) and by dividing by $\sqrt{2}$ this gave the standard error involved in using a given observed TAE area-mean to represent the long-term climatic wind-normalised mean over the area of all TAEs of that given type. This figure appears as $\sigma_{2,3}$ in Table 5.3, and from its square $C^2_{0,3}$ was calculated by subtracting $C^2_{1,0}$, $C^2_{2,0}$ and $C^2_{0,2}$.

With all six component variances evaluated, the 'addition of variances' principle allows the remainder of the nine types of sampling error in the matrix to be estimated. The matrix (Table 5.3) is itself of substantive interest in that it constitutes a unique system for determining, comparing and contrasting the types and magnitudes of sampling error encountered in ambient noise surveys in general. In the context of this research its particular value was demonstrated in its application to the statistical test of the TAE hypothesis. Section 5.2.2 of the main text describes the necessity for the data upon which the F-test was performed to be corrected for bias arising from the method of sampling, and the corrections were applied through data derived from the sampling errors matrix. The main text argues that the observed between-TAE variance B also includes the between-day temporal variance; while the component due to windspeed changes is eliminated by using normalised data, the component $C^2_{2,0}$ due to unspecified causes remains. Using the matrix a corrected value B' was obtained from

$$B' = B - C^2_{2,0} \qquad \text{B.6}$$

In the case of the observed within-TAE variance W it is argued in the main text that the component of variance $C^2_{0,3}$ existing between TAE of the same type is not included. The matrix again allowed a corrected value W' to be obtained, from

$$W' = W + C^2_{0,2} \qquad \text{B.7}$$

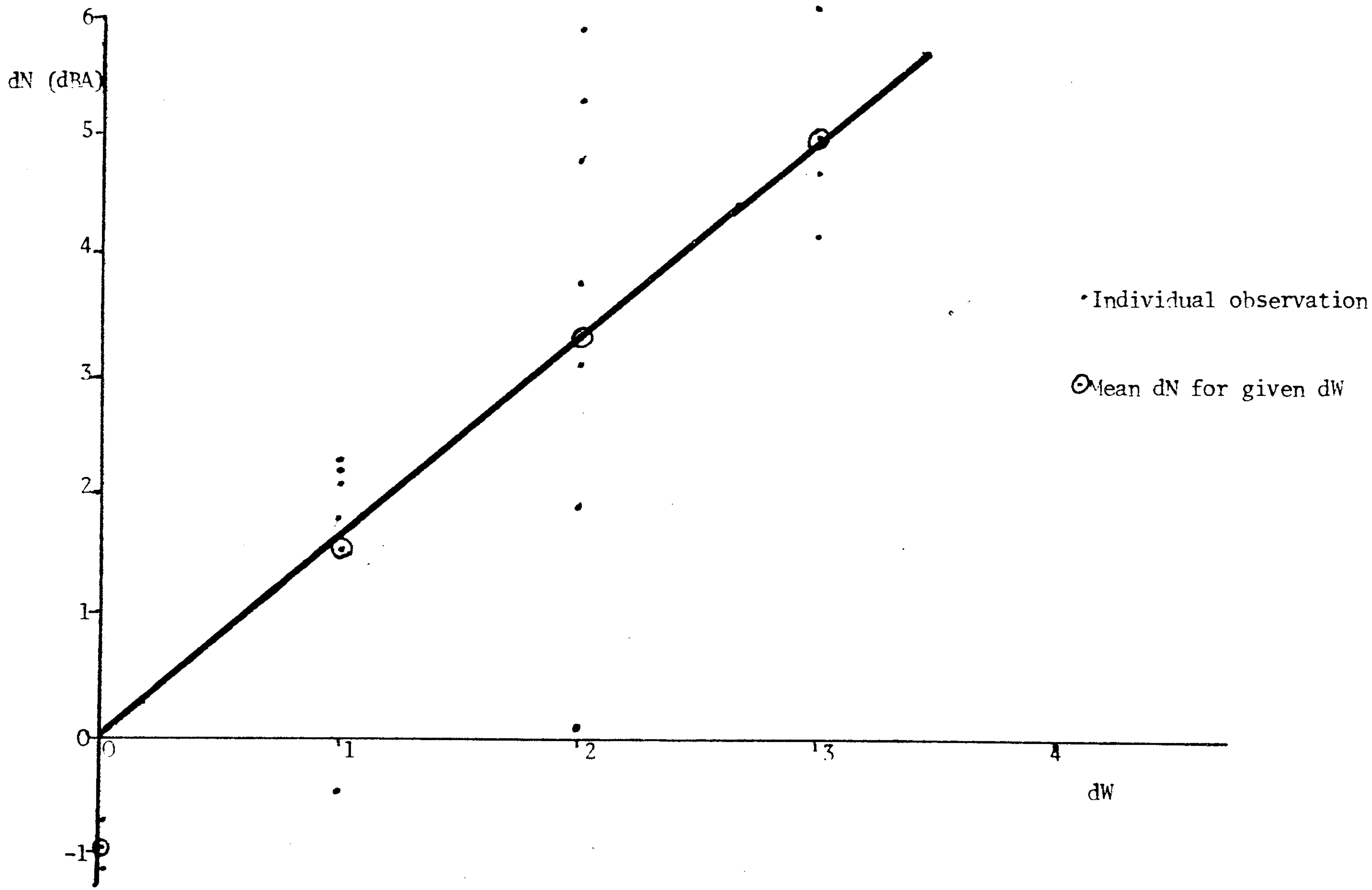
In this way the sampling errors matrix was applied to eliminate the biases encountered in the straightforward use of the observed data; without this facility the results of the key case study hypothesis test would have been technically invalid.

B.5 DEVELOPMENT OF THE WINDSPEED-NOISE MODEL

Since all the data used in the case study were normalised to a 'light wind' condition, it is evident that the windspeed-noise model through which this normalisation was achieved is of critical importance. It was developed empirically through data describing the changes of noise level observed at the 140 sites in the Phase 3 survey and, in accordance with the general principles of the research, used the simplest and most readily measured parameters. Thus changes in UNL and LNL were related simply to the observed changes in windspeed measured on the Beaufort scale (Table A.1, Appendix A), resulting in the simple 'windspeed-noise prediction models' given in equations 5.2 and 5.3 of section 5.4.1.

Section 5.4.1 stated four empirically-derived hypotheses which were taken together as a basis for the formulation of a small number of possible model specifications; these were then tested and calibrated through regression analyses using the data already described, and their performances evaluated in order to select the specification with the best empirical performance. The first two hypotheses together propose, essentially, that for any given ambient noise level the numerical (dBA) change in noise due to windspeed is linearly related to the change in windspeed as measured on the Beaufort Scale. The basis for this suggestion, which is highly simplified in view of the theoretical complexity of the issue as advanced in the main text, was entirely empirical and rested upon the data shown in Fig. B.5. The figure shows data for those sites where the lowest of the pairs of noise indicator values (relating in this case to LNL) observed on the two occasions lay in the range 40-50 dBA,

Fig. B.5 Variation in dN with dW for constant LNL (range 40-50 dBA).



and plots the observed magnitude dN of the difference in the two noise levels against the observed magnitude of the difference dW in the Beaufort Scale windspeed. The empirical relationship, despite considerable residual error, approximates closely to linearity.[1] The advantage of making this assumption is that $\frac{dN}{dW}$ is independent of W, and therefore the empirical calibration exercise relating dN to dW requires considerably less data than would be the case if the relationship were taken to be non-linear. In that event $\frac{dN}{dW}$ would be a function of W and it would be necessary to calibrate the relationship for a range of values of W; under the linear assumption, values of dW may be pooled, as was done to achieve Fig. B.5, and a relationship derived to apply equally at all values of W.

The third assumption, that the effect of windspeed on noise levels was operative only for windspeeds in excess of Beaufort Scale 2, originated directly from the subjective appraisal of the surveyor; in other words it was the surveyor's opinion that at Beaufort Scales 2 and below, no sound that could possibly be attributable to the effects of wind was discernible. The fourth assumption is consistent with the idea that windspeed has the effect of adding a noise level to the ambient noise level, N, that exists in the absence of wind, and thus in accordance with theory states that the observed increase in ambient noise level, dN, is dependent upon the level of N. From this and the foregoing it is evident that the assumptions state that

$$dN = f(W,N)$$

where $W = w - 2$ for Beaufort Scale windspeed w and $w > 2$, and $W = 0$ for $w \leqslant 2$. The empirical evidence is that the functional relationship of W is linear. If the notion that windspeed effectively adds a noise level to a pre-existing ambient level is valid, the functional relationship of dN

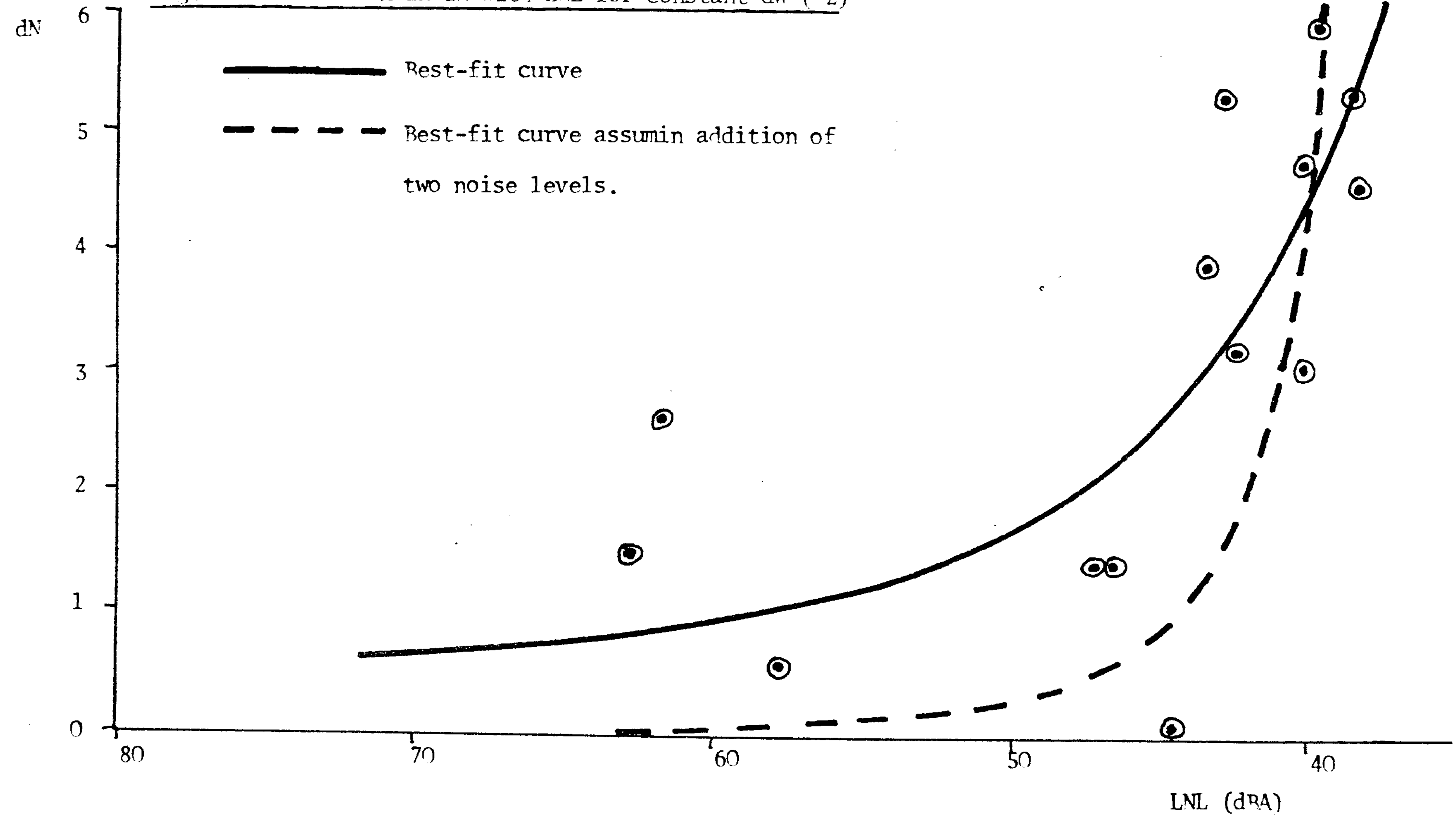
---

1. This is especially evident when, as shown in the figure, the 'best fit' relationship is drawn through the origin as is theoretically necessary.

against N (for a given dW) will be non-linear. This assumption was examined empirically through the data shown in Fig. B.6, where with dW = 2 a non-linear relationship between dN and N (in this case LNL) is indeed evident. The same data may also be used to examine the theoretical basis for the possible causes of wind-induced increases in ambient noise levels. The main text, section 5.4.1, has discussed two possible types of cause: (a) additional noise created directly by the action of wind upon certain features of the physical environment, such as trees, buildings and telegraph wires, and (b) atmospheric refraction and reflection back to ground of 'normal' ambient noise not caused by wind, the degree of which effect is assumed to be proportional to ground-level windspeed as an indicator of the causal factors, such as windspeed gradient. Evidently, cause (a) would contribute an additional wind-induced noise level which was independent of N and related solely to W, and cause (b) would contribute an additional wind-induced noise level proportional to N. Thus, if the empirically-observed wind-induced increases in ambient noise levels were to be due solely to the first cause then the relationship between dN and N would conform precisely to the well-known formula describing the simple addition of two independent noise levels (e.g. CUNNIFF 1977). A curve appropriate to this formula is fitted to the data in Fig. B.6, from which it is evident that the proposed relationship significantly underestimates the value of dN at the higher levels of N[1]. The 'best fit' curve, drawn manually, implies an additional effect consistent with a second causal factor dependent upon N. Consequently the empirical evidence was taken to support the general conclusion, derived theoretically in the main text, that wind-induced increases in ambient noise levels are due to a complex interaction of causes, such that a theoretically-derived model specification is infeasible without further extensive research at both theoretical and

1. Although this conclusion is based on only limited data in Fig. B.6, it was supplemented by the data for other values of dW.

Fig. B.6 Variation in dN with LNL for constant dW (=2)



empirical levels.

A guide to the possible future development of a theoretical model was made by considering the first possible cause alone, and the resulting model is presented shortly. For the immediate needs of the research however the empirical approach was pursued by testing a range of possible models involving relationships between dN, and product factors of W and non-linear expressions of N. The three most fruitful of these models were:

$$dN = X_1 \, W \left(e^{\left(\frac{75-N}{10}\right)} - 1 \right) \qquad B.8$$

$$dN = X_2 \, W \left(\frac{75-N}{10} \right)^2 \qquad B.9$$

$$dN = X_3 \, W \log \left(\frac{75-N}{10} + 1 \right) \qquad B.10$$

where X_1, X_2 and X_3 are calibration constants. The number 75 appears because the available data suggested that this is the upper limit to the noise levels which are detectably affected by the range of windspeeds (up to Beaufort Scale 6) considered in the study. The divisor 10 in the common factor $\frac{75-N}{10}$ appears arbitrarily in the above examples (and could be absorbed into X); its role was operative only in other model formulations not discussed here,[1] and its presence in the equations shown is due merely to the fact that for computational simplicity all models were tested upon this same common transformation of N.

The simplicity of the method for testing and evaluating the performances of the various possible empirical models derives from the fact that the independent 'predictor' variables form a single function the variation of which may be compared with that of dN through simple regression analysis.

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1. In all, twelve different model formulations were tested, and those which were the least effective in explaining between-day variance are omitted from the discussion.

The empirical tests were performed separately for UNL and LNL upon the data obtained at the 140 sites; dN was obtained by subtracting the second observed site-mean from the first, W was represented by dW, the change in windspeed which was obtained by subtracting the second observed value of W from the first, and N was obtained from the lowest of the two observed noise levels (this approximated to the ambient level in the absence of wind since in most cases the lowest noise level corresponded to a Beaufort Scale of 2 or less, and in the remainder the error was estimated to be less than 5%). Regression of the single transformed independent function against dN as the dependent variable was performed upon the Aston University ICL 1904S computer using the standard ICL XDS3 macro package for regression analysis. In addition to conducting the regression for the site-mean data, the models were also regressed upon the location-mean and area-mean data. This was not because models calibrated on this data were to be used in the research - indeed the direct application of such models to spatially-averaged noise levels would be technically invalid and in any case the number of independent observations was to small to allow a reliable calibration to be achieved. Rather, the purpose was to assist in the criteria for selection of the most appropriate model formulation; a number of criteria were set up to provide a basis for this selection process, and one of these stated that a reliable model should produce comparable regression coefficients (X) at site, location and area-mean levels. Some of the models produced coefficients differing by more than an order of magnitude, while the model eventually selected (Eqn. B.9) showed very similar coefficients, as shown in the regression results in Table 5.7 in the main text. There were three further selection criteria: that the regression constant was as near as possible to zero, that the correlation coefficient, r, was maximised, and that the residual error was minimised. From a joint consideration of these criteria, the model given by Eqn. B.9 was selected - in fact it performed the best of all models with respect to each criterion - and regression coefficients of 0.15 and 0.13 were obtained for UNL and LNL respectively, giving a calibrated model predicting the decibel increase in ambient noise levels, dN, due to windspeed W, for ambient wind-free noise levels N, as in Table 5.6 and discussed in the accompanying main text.

The possibility of developing a theoretically-derived model for predicting the effect of windspeed upon ambient noise levels as suggested earlier was examined through a consideration of the first possible type of cause only, since knowledge of the physical processes that might be involved in the second type of cause is not sufficiently advanced to allow a proper mathematical treatment. What follows must therefore be taken only as a guideline for a comprehensive future approach which may be achieved from improved knowledge of atmospheric acoustics.

The decibel measure of the sound pressure level, which is the acoustic quantity used in ambient noise measurement, is defined such that a given sound with r.m.s. pressure level p is represented by a decibel value L given by

$$L = 10 \log\left(\frac{p^2}{p_o^2}\right) \qquad B.11$$

where p_o is a reference pressure (CUNNIFF 1977). The energy in a given sound wave is proportional to the intensity I of the wave, and I is in turn proportional to p^2. Now under the hypothesis expressed as the first possible cause of wind-induced noise, a given speed of wind creates additional sound the energy of which will be proportional to the kinetic energy of the wind itself. Thus if the wind has a mean velocity V, the intensity I_w of the sound waves that it excites will be proportional to V^2 since the wind kinetic energy is proportional to V^2, i.e.

$$I_w \propto V^2 \qquad B.12$$

Research has shown that the Beaufort Scale measures of windspeed, W, are related to precise mean measured velocities by the approximation

$$W \triangleq V^{2/3} \qquad B.13$$

(AIR MINISTRY 1962)

Thus,

$$I_W \propto W^{9/4}$$
$$= K\, W^{9/4} \qquad B.14$$

where K is a constant.

Now, consider a wind of Beaufort Scale W blowing at a site where, in the absence of wind, an ambient sound level of intensity I_A exists. The actual intensity of the sound observed at the site, I_X, will be given by

$$I_X = I_A + I_W \qquad B.15$$

From B.11 it is evident that the decibel ambient noise level <u>in the absence of wind</u>, N_A, is given by

$$N_A = 10 \log\left(\frac{I_A}{I_0}\right) \qquad B.15$$

where I_o is a reference intensity equivalent to p_o; and the decibel ambient noise level <u>when a wind of speed W is blowing</u>, N_X, is given by

$$N_X = 10 \log\left(\frac{I_A + I_W}{I_o}\right)$$

Thus the decibel increase in observed noise level, N, caused by a wind of speed W is given by

$$N = N_X - N_A$$
$$= 10 \log\left(\frac{I_A + I_W}{I_o}\right) - 10 \log\left(\frac{I_A}{I_0}\right)$$
$$= 10 \log\left(1 + \frac{I_W}{I_A}\right) \qquad B.16$$

I_W is given by Eqn. B.14, while from Eqn. B.15,

$$I_A = I_o . 10^{\frac{N_A}{10}}$$

Substituting for I_W and I_A, the decibel increase in noise level caused by a wind of speed W at a site where in the absence of wind the ambient noise level is N_A, if given by

$$N = 10 \log \left(1 + \frac{K^1 W^{9/4}}{10^{\frac{NA}{10}}} \right) \qquad B.17$$

where K^1 is a constant.

Equation B.17 is therefore a theoretically-derived model for predicting N in terms of W and N_A, the same parameters as were used in the empirical model, Eqn. B.9. A properly comprehensive theoretical model would require the value for I_W in Eqn. B.14 to include an additional element due to the second type of cause, which was excluded from the above because of the paucity of current knowledge.

APPENDIX C

TECHNICAL ISSUES RELATING TO THE SULPHUR DIOXIDE STUDY

C.0 INTRODUCTION

This appendix sets out a number of technical issues supporting the study of sulphur dioxide air pollution conditions, and in particular the development of the urban diffusion model. The first of the four sections in the Appendix examines the temporal variations in urban sulphur dioxide levels in relation to the possible causes; the second deals mainly with the question of the validity of treating urban air pollution at the 'area-source' level alone. Factors concerning the adaptation of the Sharma model to the research context are described in the third section and the specially-written FORTRAN programme is given, while technical matters in the use of the secondary-source data to calibrate the model are discussed in the final section together with the method for estimating the confidence intervals of the urban diffusion model over its working range.

C.1 TEMPORAL VARIATION IN AMBIENT SULPHUR DIOXIDE LEVELS

A summary of the causes and cycles of temporal variation in urban ambient sulphur dioxide concentrations was given in section 6.1.2 of the main text in connection with the argument for selecting the long-term seasonal ('Winter') period as the 'climatic' period the mean concentrations for which were to be represented in the research. Associated with this choice and the factors affecting it, was the concomitant necessity for continuously-monitored data covering the whole period, rather than short-term sample data such as that used in the ambient noise study; resulting from this it was seen to be necessary to use secondary-source National Survey data, because of the unfeasibility of a long term monitoring survey being conducted in the research. The ramifications of the temporal variability of air pollution concentrations thus significantly affected the nature of the empirical case study, and so the variations themselves warrent close examination.

As the main text observes, three distinct phases of variation are evident: annual, between-day and within-day. These are treated here in turn, in connection with the relevant meteorological and emissions factors which determine them.

Fig. C.1 illustrates the general annual trend in the emissions of

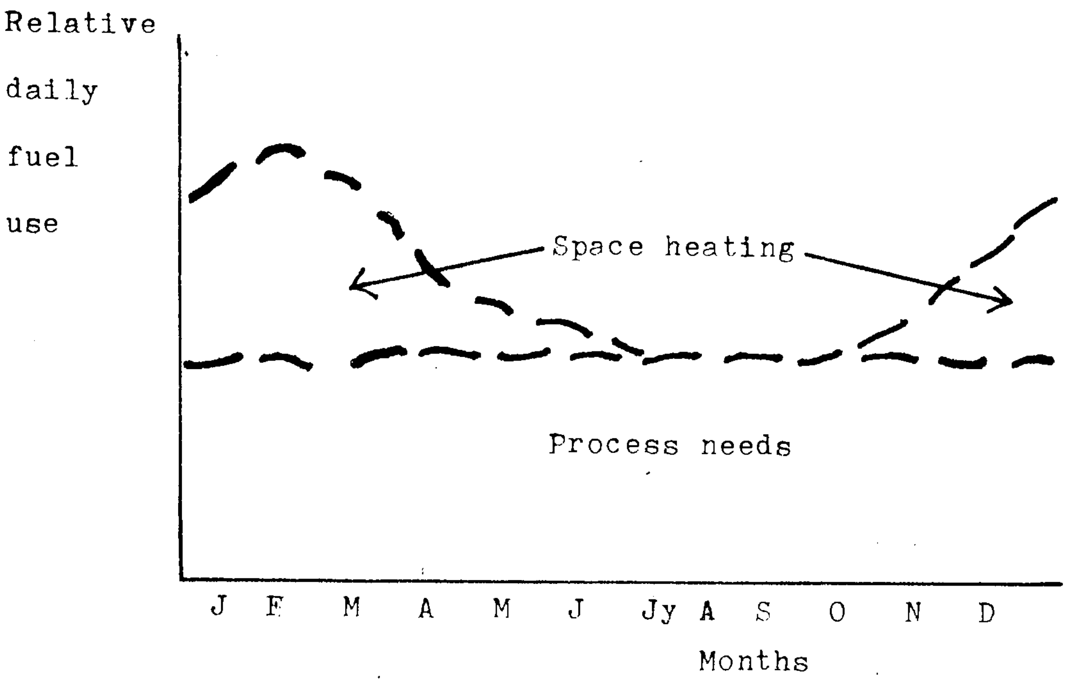


Fig. C.1 Typical annual variation in SO_2 emissions from the two types of source. (after BALL 1976).

sulphur dioxide. In fact two distinct types of activity cause emission: industrial processes, where the requirement is for power, and the industrial, commercial and domestic activities which make demands for space-heating. The former demand is approximately constant taken over the year as a whole, but the latter is a seasonal factor which varies with air temperature. Indeed research (e.g. MARSH and FOSTER 1967) has generally shown that sulphur dioxide emissions from the latter type of source may be correlated with a parameter termed the 'degree-day', which describes the

Fig. C.2 Variation in monthly mean SO_2 levels (average of all WMMC sites), and degree days below 60°F(16°C), for 1975/6.

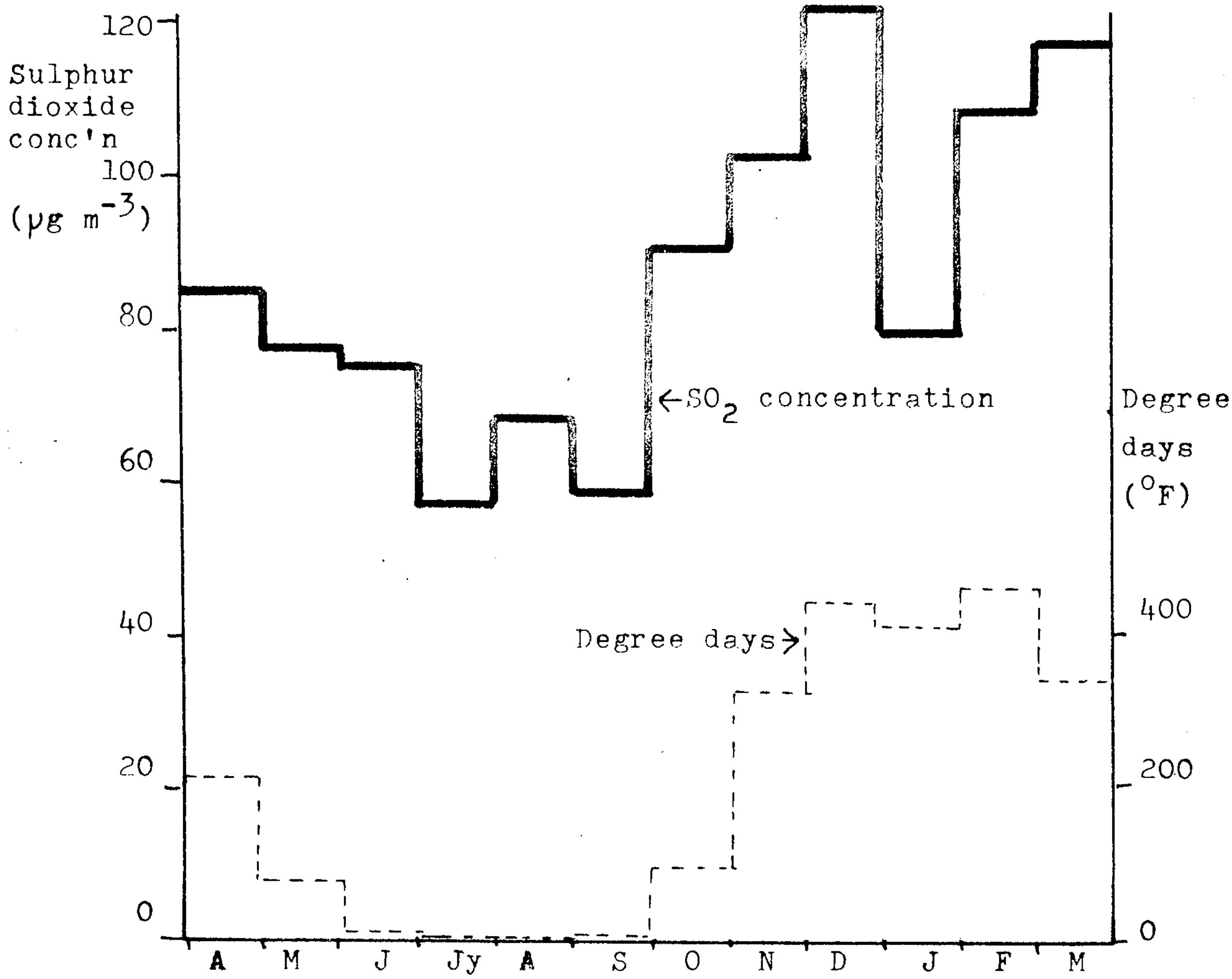
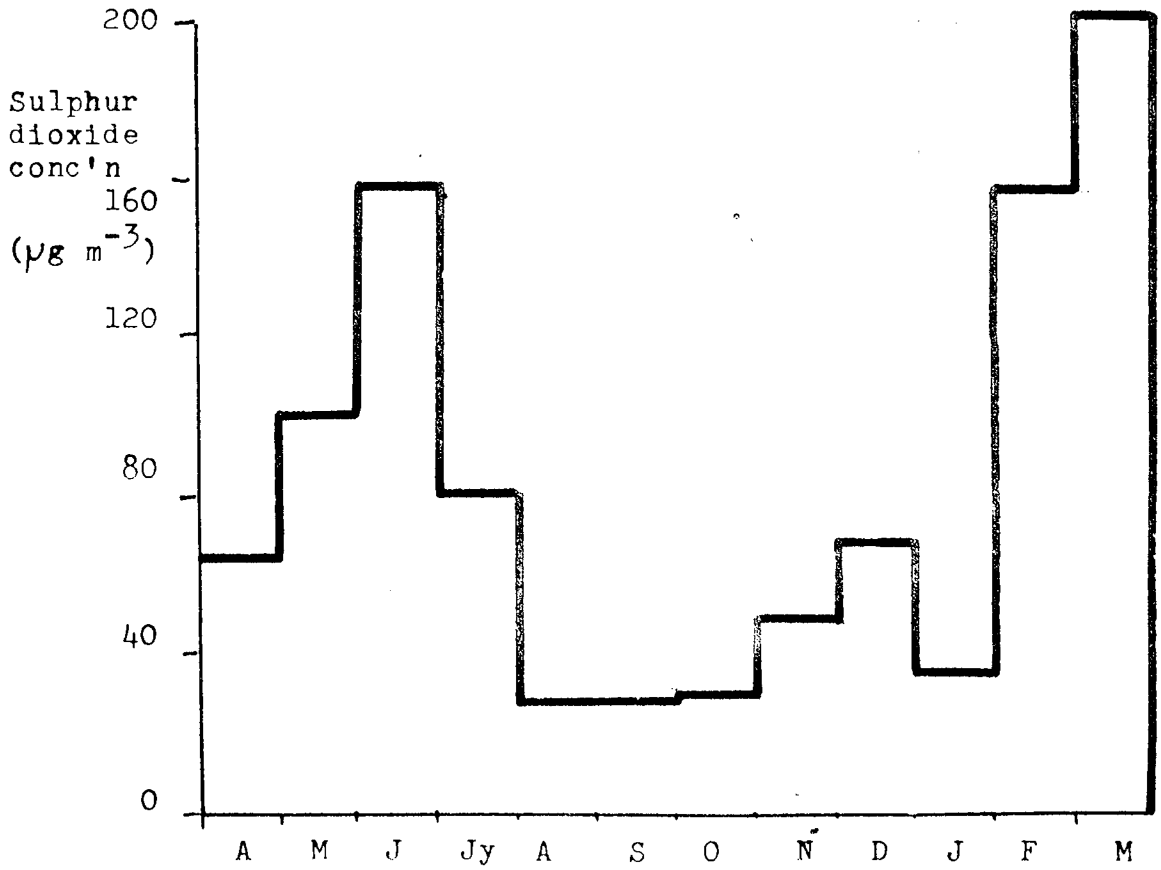


Fig. C.3 Unusual annual variation in SO_2 levels: site Halesowen 6 (1968/9).



number of degrees by which a given day's temperature fails to reach 16°C. Fig. C.2 shows the monthly mean sulphur dioxide concentrations for the mean of all 36 National Survey sites in the WMMC for the year 1975/6 (the Winter means for this year were used in the urban diffusion model). The total monthly 'degree days' are also shown and it is seen that in general terms the trend over the year follows a pattern consistent with the emissions theory of Fig. C.1. However the apparently anomalous fall in concentrations in January 1976 should be noted, as this is not an uncommon feature in stormy midwinter periods when persistently windy and unstable conditions ensure that the lower atmosphere is particularly well ventilated. The converse is true of the persistent settled, stable, anticyclomic periods common in autumn and early spring, when pollutants may accumulate in the stagnant air. Thus particularly persistent extremes of atmospheric stability may cause marked deviations from the general trend in concentrations laid down simply on the basis of the emissions cycle. Fig. C.3 shows an exceptional annual cycle recorded at the National Survey site Halesowen 6 in the year 1968/9, when very little relationship between concentrations and air temperature was observed. In general however the trend holds and it is seen to be correct to choose the 'Winter-mean' (October-March) period for the empirical study since over this period the spatial pattern of pollution due both to process and space heating needs will be best revealed.

(a) Between-day variations

The above discussion has indicated the importance of atmospheric stability in determining the ground-level concentrations resulting from a given rate of emission, and this factor is even more important in determining the day-to-day variations in sulphur dioxide concentrations. Not only atmospheric stability but changes in wind direction too have this effect. Fig. C.4 shows an example of the extent of this variability, demonstrated by the daily mean concentrations recorded at the National Survey site

Fig. C.4 Variations in daily mean sulphur dioxide concentrations for a period in April 1977; site Birmingham 26

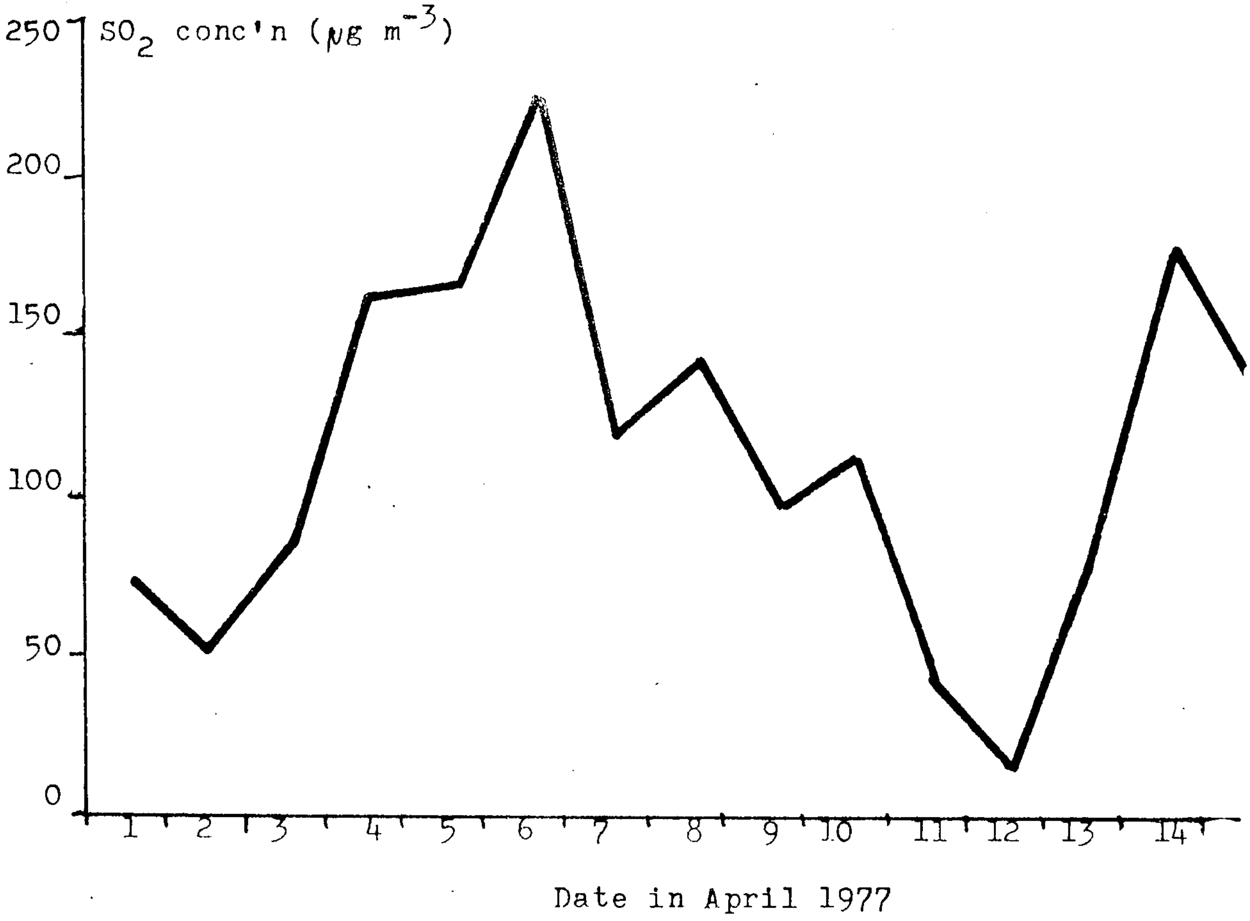
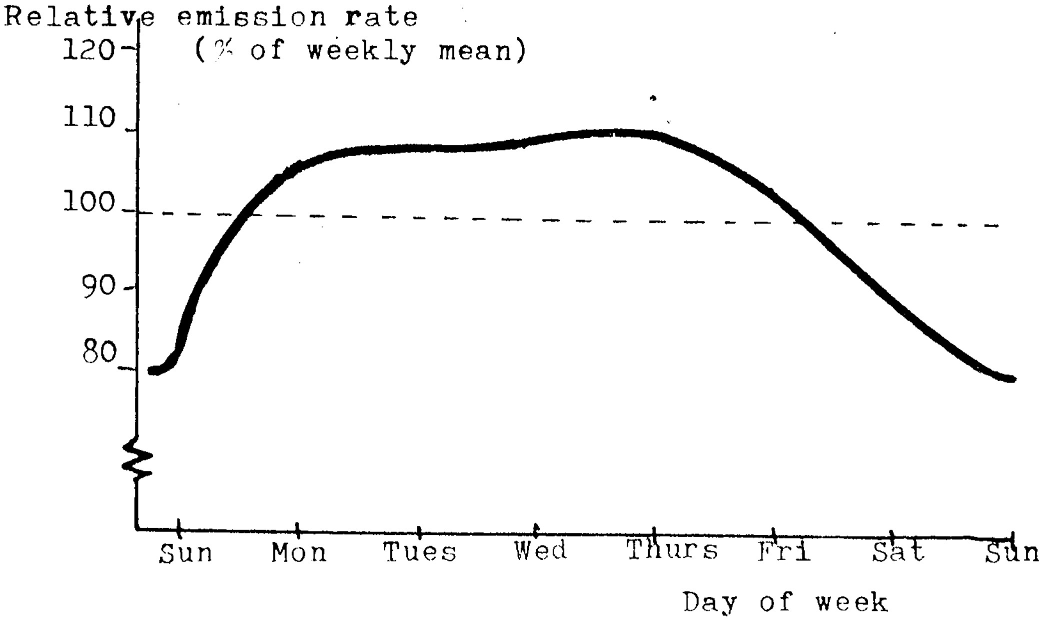


Fig C.5 Example of typical weekly trend in sulphur dioxide emissions (after DEMUYNCK and DAMS 1975).



Birmingham 26 for the first fifteen days of April 1977. Concentrations vary from 230 ug m^{-3} to 17 ug m^{-3} within a period of six days and although this is an unusually large variability it is by no means uncommon at any time of year, and reflects the dramatic effect which changes in meteorological conditions may have over short periods. Clearly the mean concentration observed on any one day cannot be used in any way as a guide to a longer-term (monthly or seasonal) mean, and the complex causal factors involved render unfeasible the use of prediction models to normalise conditions as was done in the ambient noise study. The only between-day variation to follow a detectable cycle is that associated with the weekly emissions cycle. Fig. C.5 shows this association as observed in a study by DEMUYNCK and DAMS (1975), and it has also been referenced by MEETHAM (1945). The emissions due to industrial process needs and large-scale commercial and industrial space-heating are the most significant causes of this phenomenon.

(b) Within-day variation

Variations between the mean concentrations of the hours of a single day can be even more dramatic than those shown in Fig. C.4. Figs. C.6 and C.7 show exceptional and more typical examples respectively, both resulting from the studies of Sheffield conducted by GARNETT (1967, 1971). To an extent such variations follow the gêneral pattern of emissions approximated by SMITH and JEFFREY (1975) to the cycle shown in Fig. C.8. Industrial process emission occurs predominantly in the working-day period (0800 - 1700) while large-scale space heating emissions peak in the 0600-1000 period; morning and evening domestic emissions are also important especially in areas where untreated domestic coal consumption is common. Clearly each of these sources has its own particular form of the general pattern of Fig. C.8, and the resulting cycle will depend on the urban fabric nature of the location of interest and the degree-day temperature

Fig. C.6 Example of exceptional diurnal variation in air pollution conditions (Source: GARNETT 1967; episode on 6.11.65)

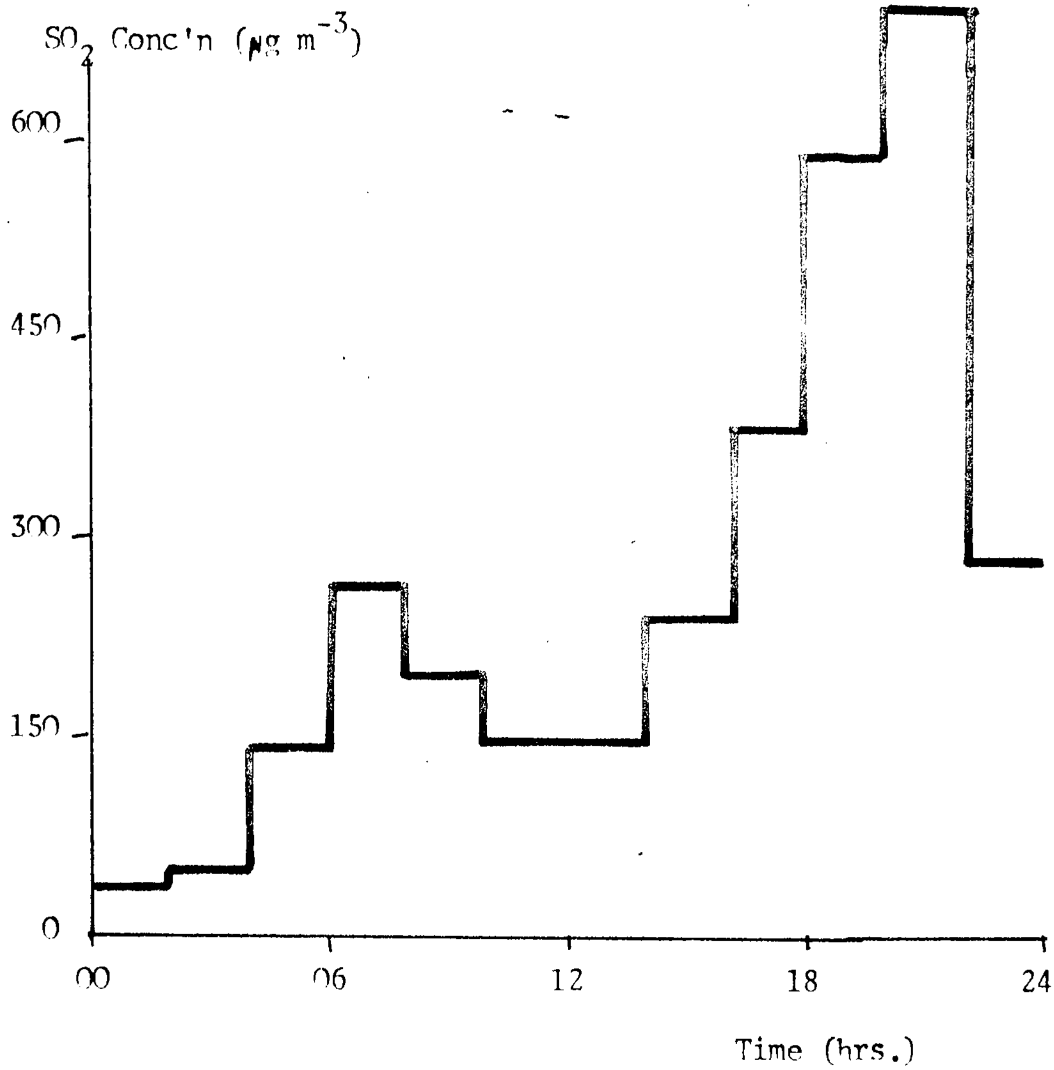
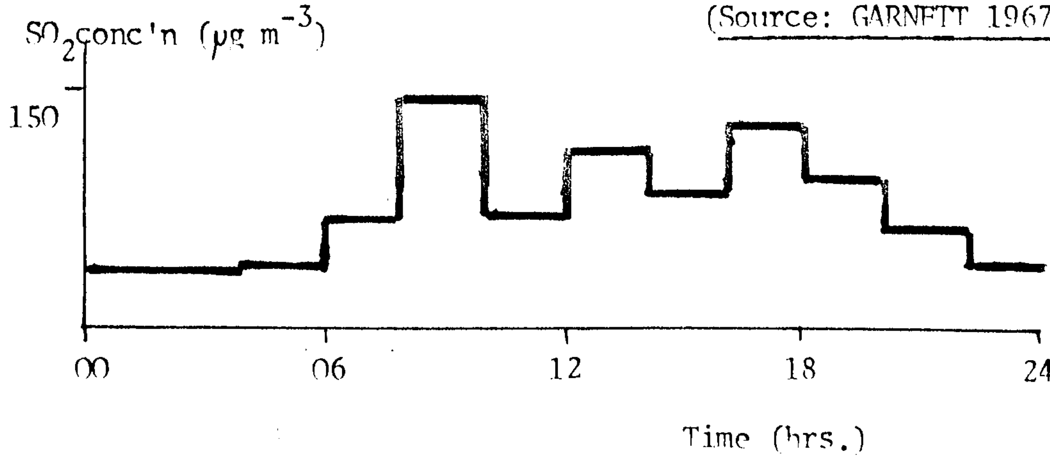


Fig. C.7 Typical diural variation in air pollution conditions (Source: GARNETT 1967).



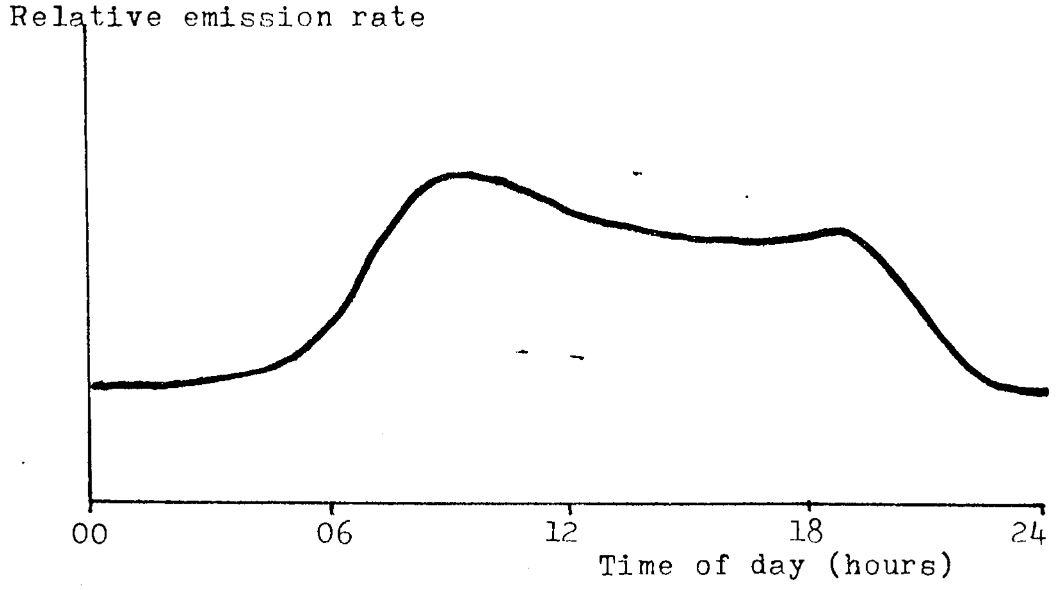


Fig. C.8 Typical diurnal SO_2 emissions cycle (after SMITH and JEFFREY 1975).

inasmuch as this affects the relative importance of the different types of source.

Emission factors are however only partly responsible for the 'bi-modal' form of the diurnal cycle, and research (e.g. GARNETT 1967, 1971, 1973) has shown the diurnal cycle in the vertical temperature lapse rate[1] in the lower atmosphere to be critically important. Commonly the night-time cooling of the earth's surface, causes a neutral or negative lapse rate, or 'inversion'(i,e. temperature rises with altitude in the lower atmosphere); this eliminates vertical atmospheric turbulance and mitigates against the dispersal of pollutants which thus accumulate in the lower atmosphere. In the period 1-3 hours after dawn when the heating effect of the sun causes a switch to a positive lapse rate, the stability layers are broken down by thermal turbulance and trapped pollutants are brought to ground in what is termed a 'fumigation event', to give

1. The 'lapse rate' is the rate at which temperature changes with height above ground level.

generally the highest ground level concentrations of the day. Folowing this, continued turbulance leads to relatively low early afternoon concentrations before a second rise becomes evident around sunset in association with the first re-formation of night-time stability layers. Clearly this cycle is disrupted in disturbed and stormy meteorological conditions when positive (unstable) lapse rates, and therefore well-ventilated conditions, predominate through day and night. Further complications in short-term pollution variation occur in connection with anomalous events such as the well-recognised 'inversion episodes' (e.g. SCORER 1965) when the inversion lasts through day and night sometimes for up to four or five days. In association with such events, GARNETT (1969) has suggested that the very highest ground-level concentrations that may be observed in the UK occur at the end of such an episode, accompanying the switch to positive lapse rates in advance of less stable weather. This phenomenon, often lasting only an hour or two, is termed a 'fumigation episode' and has led to exceptional hourly concentrations such as the 5,800 $\mu g\ m^{-3}$ recorded by GARNETT (1969).

The above serves to illustrate the complexity and interrelatedness of the emissions and meteorological factors in determining temporal air pollution variations, and the high degree of unsystematic variability in pollution concentrations that results. These matters played a large part in the decision to use long-term (Winter-mean) monitored data, obtained from the National Survey as a secondary source, as the basis for the empirical case study.

C.2 AREA-SOURCE PREDICTION MODELS

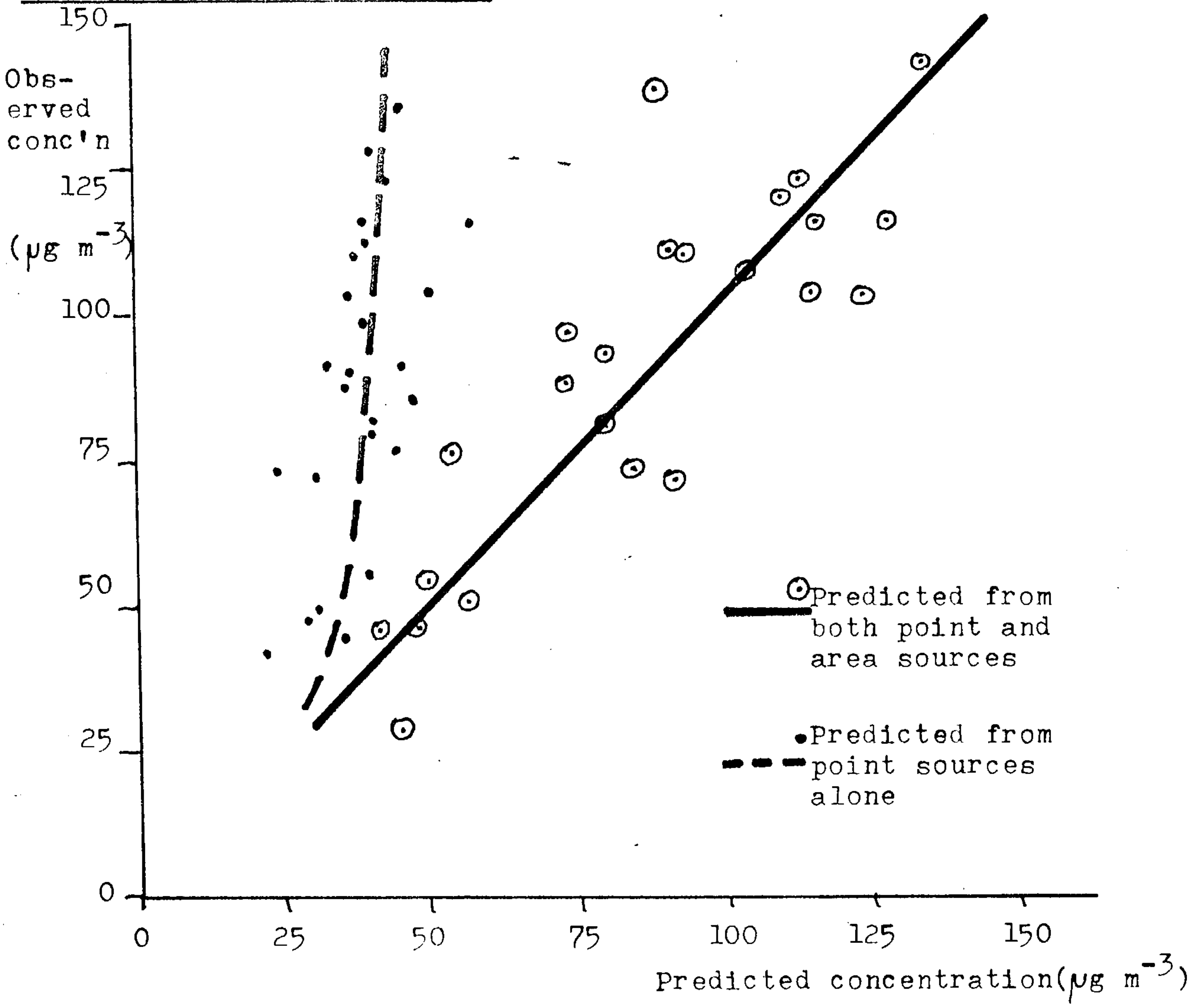
Section 6.2 of the main text examines the methods for mapping sulphur dioxide conditions over large urban areas. Both measurement-based and predictive modelling techniques have been used and it is seen that the TAE methodology is an example of the 'area-based emission proportionality model' (or 'Gifford Model'), a predictive approach based on the theory that an area's total emissions may be used to determine its average concentrations. The usefulness of this approach in relation to the objectives of the research has already been defended in the referenced section of the main text, and the point is further emphasised in the classification of air pollution models shown in Tables C.1(a) and (b), a system due to BENARIE (1976). Clearly the main objective of the research is to provide a model which fulfills the 'air management' category of use as given in Table C.1(a), with the three special purposes outlined in the third column summing up the general applications prescribed in Chapter 1.1. Of the range of models denoted in the final column as being useful for these purposes, number 8 (as listed in Table C.1(b)) is equivalent to the TAE methodology, although Benarie's term 'demographic data' is only broadly descriptive of the urban fabric categories used in the TAE methodology. It is seen that this model number 8 is suitable for long-term predictions and requires a minimal amount of meteorological data.

As discussed at the beginning of section 6.4.1, the effectiveness of area-source sulphur dioxide pollution models is due to the fact that in comparison with point-source emissions, area source emissions have a disproportionately strong effect on ground-level concentrations. This is because point-source emissions, from the prominent stacks such as those of industry and power stations, undergo greater dispersion before the pollutants reach ground level. Thus, while Fig. 6.1 in the main text reveals that the majority of the sulphur dioxide emitted in the UK comes from point sources, and in London BALL (1978a) has estimated that 70% of the emission mass can be attributed to point sources discharging in excess of 30 tons per annum, nevertheless it is the low-level area source emissions (predominantly commercial and domestic in nature) which determine spatial variability within areas the size of a conurbation. At this scale the effect of the point sources is essentially in contributing a spatially

constant 'background level' to the area, upon which spatial variability is superimposed as a result of spatial variation in area-source emissions. The data published by PRAHM and CHRISTENSEN (1977) were analysed in the research in order to substantiate this proposition. The data relate to the application of the CDM (explained in section 6.2.1 of the main text) to sulphur dioxide emissions in Copenhagen. Fig. C.9 shows the relationship between observed and predicted concentrations at a comprehensive sample frame of 23 sites for two types of prediction, one using both point and area source data (in which a linear relationship with a slope of unity is observed, indicating reliable prediction), and the other using the predictions resulting from considering point-source emissions alone; in this latter case it is seen that the predicted concentrations are almost constant across the sample frame, implying that the assumption of a spatially constant 'background level' in urban areas resulting from point sources is valid.

The above was considered in the research to provide sufficient evidence to justify the pursuit of an area-based prediction methodology. The main text shows that examples of this type of approach are quite commonplace but frequently the prerequisite area-source emission inventory is either extremely complex (expressed in actual emission volume terms such as tons of SO_2 per annum, a quality of data not easily obtained by the average local authority), or highly simplified (such as population density, housing density etc.). The substitution of an emission inventory expressed in terms of urban fabric categories, as applied in this research, is a unique intermediate approach which combines simplicity and the use of readily available data with a thorough and comprehensive theoretical basis. Only two other published studies attempt a comparable approach. MYRUP and ROGERS (1976) have developed an area-based prediction model using the urban fabric categories given in Table C.2;

Fig. C.9 Relative contribution of point and area sources in the Prahm and Christensen study



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Source: Myrup and Rogers (1976)

(N.B. The category order does not imply any ranking in terms of air pollution concentrations)

however this model was designed specifically for traffic-related pollutants and is not thus directly applicable to the sulphur dioxide pattern of emissions. The WARREN SPRING LABORATORY (1974) have developed the urban fabric classification given in Table C.3, but have not refined it into a prediction model by associating each category with a typical emission strength or mean concentration. Nevertheless it represents the most comparable approach to that used in the research, and the classification in Table C.3 played a considerable part in the development and definition

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C.3 ISSUES IN APPLYING THE SHARMA MODEL TO THE RESEARCH

Section 6.4.1 of the main text makes the argument for introducing the Sharma model into the research, its role as an urban diffusion model being to provide the empirical air pollution data as the initial stage in the testing of the TAE methodology. In discussing the application of the Sharma model and its adaptation to the research it was stated that the directional effect of between-zone diffusion was assumed to be zero. In many places such an assumption becomes increasingly viable as the time-period considered increases, and over a season or longer the variation in wind directions averages out to give only a small net directional effect. Naturally the extent to which this is so depends upon the relative preponderance of the different wind directions characteristic of any one place. In the USA, POOLER (1961) and TURNER (1973) have both made the assumption of net directional neutrality, and despite the common presumption that the UK has a predominantly south-westerly wind pattern the meteorological evidence is that the net overall effect is in fact quite small. In the case study area, two meteorological stations are maintained; that at Edgbaston, Birmingham, is the most centrally located, and was therefore chosen as a source of data for examining the net directional effect of wind in the WMMC. Meteorological data for the study period (1975) are given in Tables C.4(a) and (b), and the resulting 'wind-rose' is shown in Fig. C.10. The net directional effect is seen to be such

Fig. C.10. Wind rose for Birmingham (Edgbaston) 1975.

(vectors represent frequency of observed wind direction)

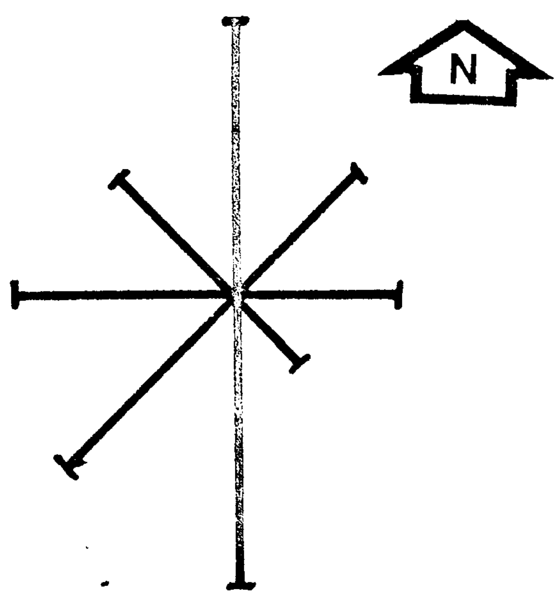


Table C.4(a) Frequency Distribution of Windspeeds (in Beaufort Scale Categories) for Edgbaston (Birmingham) Observatory, 1975

Windspeed Frequencies	Beaufort Windspeed Categories				
	0	1-3	4-5	6-7	8+
No. of days (as observed at 1500 hrs)	10	247	101	7	0
% of year	2.7	67.7	27.7	1.9	0

Table C.4(b) Frequency Distribution of Wind Directions for Edgbaston (Birmingham) Observatory, 1975

Wind Measurements	Wind Direction							
	N	NE	E	SE	S	SW	W	NW
No. of days (at 0900)	51	41	33	14	71	52	37	37
(at 1500)	60	36	39	17	56	60	49	38
(at 2100)	67	37	38	22	57	42	54	27
Total	178	114	110	53	184	154	140	102
(as %)	(17.2)	(11.0)	(10.6)	(5.1)	(17.8)	(14.9)	(13.5)	(9.9)

that in vector terms, the westerly component exceeds the easterly component by 5.8% and the southerly component exceeds the northerly component by only 0.5%; the 'wind vector' resultant is thus comparatively small - small enough to be taken as zero when the other approximations in the model are considered.[1]

1. Note that it is strictly necessary to treat not simply wind directions, but a 'joint frequency distribution' (TURNER 1973) of windspeed, wind direction and atmospheric stability, in order to consider the net directional effect of pollution diffusion. However the wind rose data alone were considered owing to the lack of any more extensive information.

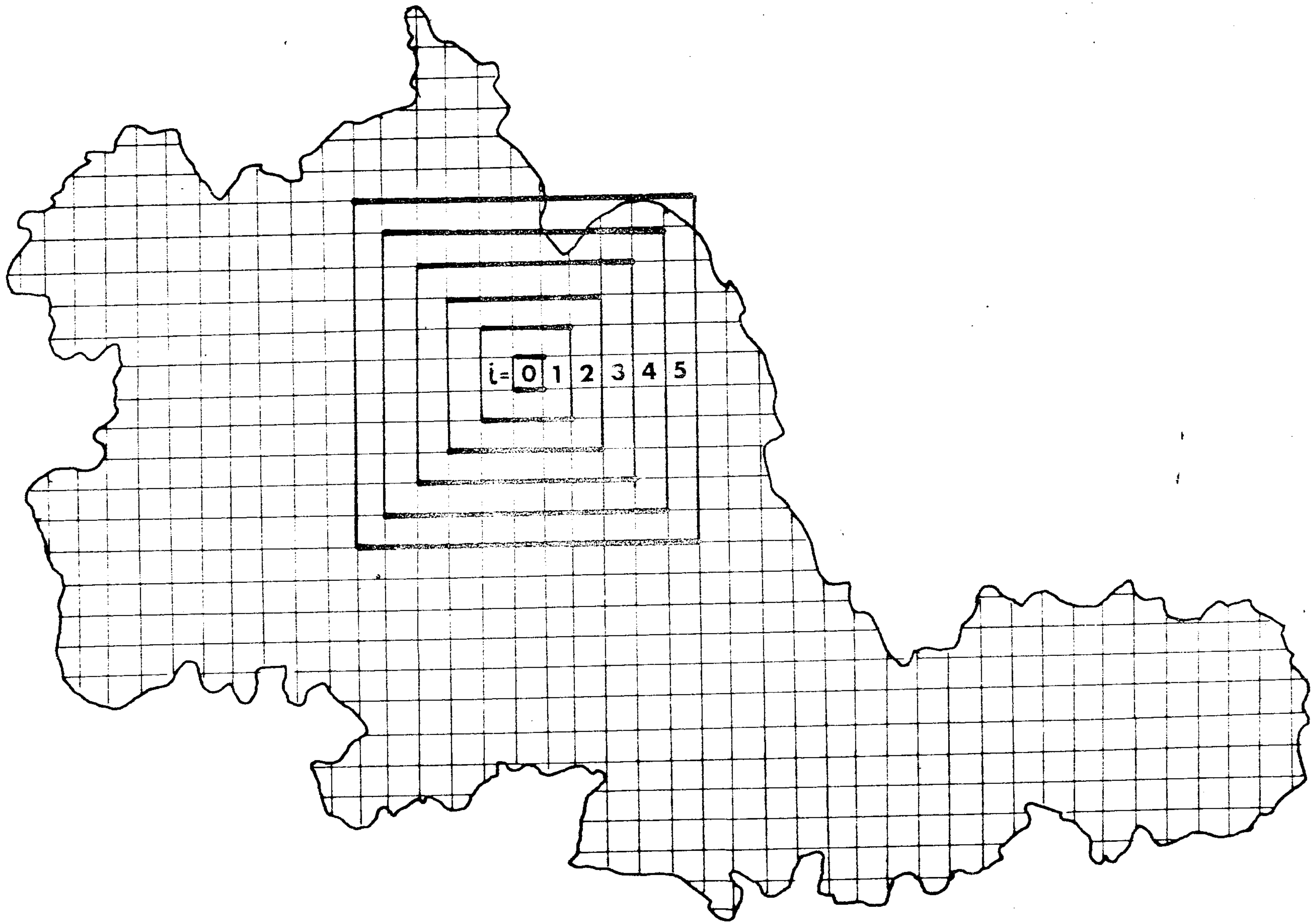


Fig. C.11. Example showing the 'catchment area' covered by the 'nested' zones i=1,5

Table C.5. FORTRAN Computer Program written especially for the Urban Diffusion Model.

```
      MASTER AIR POLLUTION
      DIMENSION LL(53,40,10),A(53,40,10),B(53,40),C(53,40),MM(53,40),N(5
     13,40)
      DO 11 J=1,40
      DO 11 I=1,53
      READ(1,10)(LL(I,J,K),K=1,10)
      DO 11 K=1,10
   11 A(I,J,K)=FLOAT(LL(I,J,K))*10.0
      KA=0
      KB=0
      KC=0
      KD=0
      KE=0
      LA=0
      LB=0
      LC=0
      LD=0
      LE=0
      WRITE(2,41)
      DO 12 J=1,40
      DO 12 I=1,53
   12 B(I,J)=0.52*A(I,J,1)+0.6*A(I,J,2)+0.33*A(I,J,3)+0.38*A(I,J,4)+0.42
     1*A(I,J,5)+0.33*A(I,J,6)+1.45*A(I,J,7)+0.9*A(I,J,8)+1.0*A(I,J,9)+0.
     18*A(I,J,10)+44.2
      DO 13 J=6,35
      DO 13 I=6,48
      C(I,J)=0.64*B(I,J)
      DO 14 M=J-1,J+1,2
      DO 14 L=I-1,I+1
   14 C(I,J)=C(I,J)+(0.12/8.0)*B(L,M)
      DO 15 L=I-1,I+1
      DO 15 M=J
   15 C(I,J)=C(I,J)+(0.12/8.0)*B(L,M)
      DO 16 M=J-2,J+2,4
      DO 16 L=I-2,I+2
   16 C(I,J)=C(I,J)+(0.09/16.0)*B(L,M)
      DO 17 L=I-2,I+2,4
      DO 17 M=J-1,J+1
   17 C(I,J)=C(I,J)+(0.09/16.0)*B(L,M)
      DO 18 M=J-3,J+3,6
      DO 18 L=I-3,I+3
   18 C(I,J)=C(I,J)+(0.06/24.0)*B(L,M)
      DO 19 L=I-3,I+3,6
      DO 19 M=J-2,J+2
   19 C(I,J)=C(I,J)+(0.06/24.0)*B(L,M)
      DO 20 M=J-4,J+4,8
      DO 20 L=I-4,I+4
   20 C(I,J)=C(I,J)+(0.05/32.0)*B(L,M)
      DO 21 L=I-4,I+4,8
      DO 21 M=J-3,J+3
   21 C(I,J)=C(I,J)+(0.05/32.0)*B(L,M)
      DO 22 M=J-5,J+5,10
      DO 22 L=I-5,I+5
   22 C(I,J)=C(I,J)+(0.04/40.0)*B(L,M)
      DO 23 L=I-5,I+5,10
      DO 23 M=J-4,J+4
   23 C(I,J)=C(I,J)+(0.04/40.0)*B(L,M)
```

Table C.5. FORTRAN Computer Program written especially for the Urban Diffusion Model (Cont.)

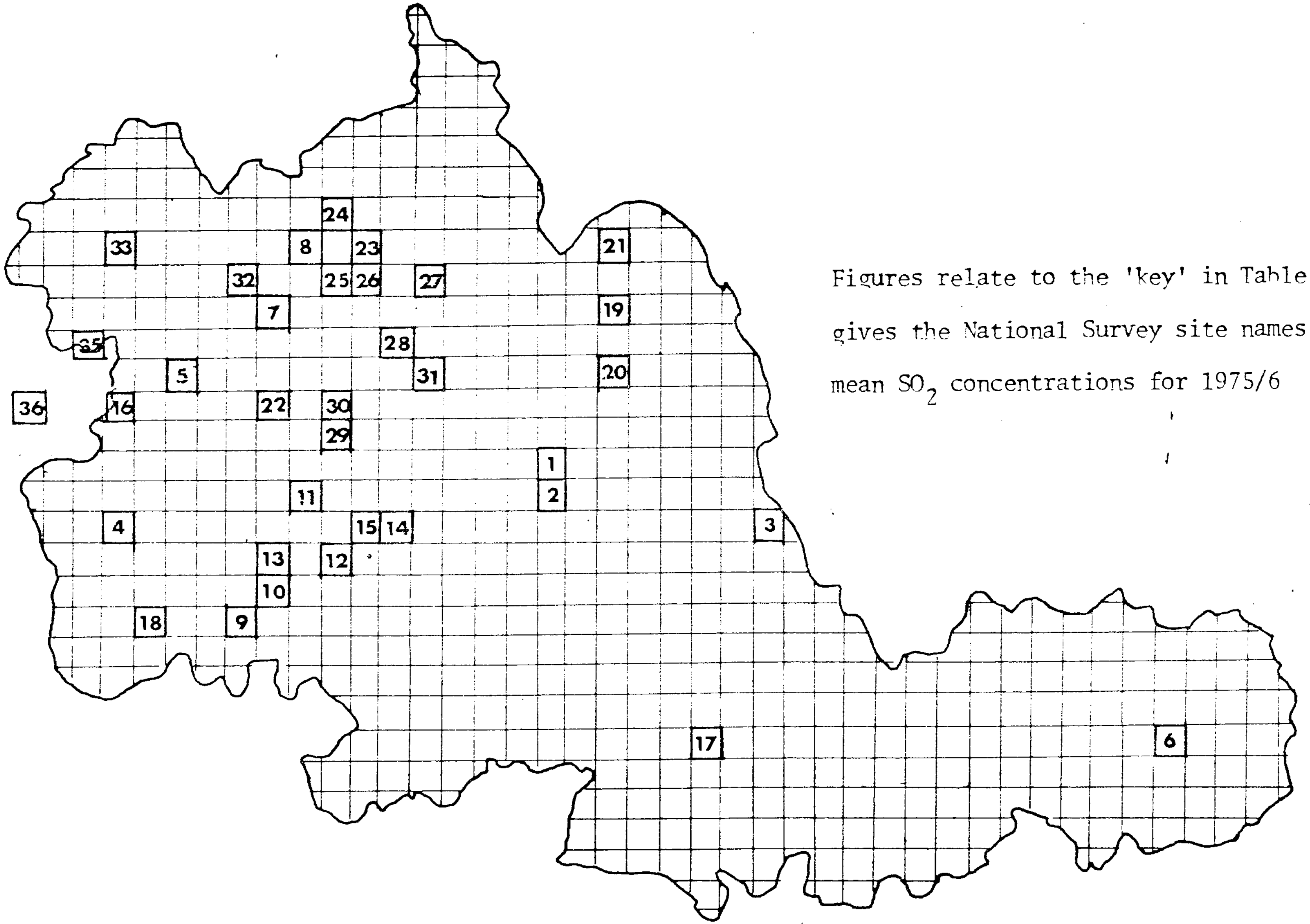
```
      IF(C(I,J).LT.60.0)MM(I,J)=5
      IF(C(I,J).GE.60.0.AND.C(I,J).LT.80.0)MM(I,J)=4
      IF(C(I,J).GE.80.0.AND.C(I,J).LT.100.0)MM(I,J)=3
      IF(C(I,J).GE.100.0.AND.C(I,J).LT.125.0)MM(I,J)=2
      IF(C(I,J).GE.125.0)MM(I,J)=1
      IF(B(I,J).LT.70.0)N(I,J)=5
      IF(B(I,J).GE.70.0.AND.B(I,J).LT.95.0)N(I,J)=4
      IF(B(I,J).GE.95.0.AND.B(I,J).LT.120.0)N(I,J)=3
      IF(B(I,J).GE.120.0.AND.B(I,J).LT.145.0)N(I,J)=2
      IF(B(I,J).GE.145.0)N(I,J)=1
      IF(N(I,J).EQ.MM(I,J)+2)KA=KA+1
      IF(N(I,J).EQ.MM(I,J)+1)KB=KB+1
      IF(N(I,J).EQ.MM(I,J))KC=KC+1
      IF(N(I,J).EQ.MM(I,J)-1)KD=KD+1
      IF(N(I,J).EQ.MM(I,J)-2)KE=KE+1
      IF(MM(I,J).EQ.1)LA=LA+1
      IF(MM(I,J).EQ.2)LB=LB+1
      IF(MM(I,J).EQ.3)LC=LC+1
      IF(MM(I,J).EQ.4)LD=LD+1
      IF(MM(I,J).EQ.5)LE=LE+1
      II=I+8
      JJ=J+4
      WRITE(2,30)II,JJ,B(I,J),C(I,J),N(I,J),MM(I,J)
   13 CONTINUE
      WRITE(2,31)LA,LB,LC,LD,LE
      MUM=(LA+LB+LC+LD+LE)
      TOT=FLOAT(MUM)/100.0
      PA=FLOAT(LA)/TOT
      PB=FLOAT(LB)/TOT
      PC=FLOAT(LC)/TOT
      PD=FLOAT(LD)/TOT
      PE=FLOAT(LE)/TOT
      WRITE(2,32)MUM,PA,PB,PC,PD,PE
      WRITE(2,33)KA,KB,KC,KD,KE
      WRITE(2,40)
      DO 24 K=6,35
      J=41-K
   24 WRITE(2,34)(MM(I,J),I=6,48)
      WRITE(2,70)
      DO 25 K=6,35
      J=41-K
   25 WRITE(2,34)(N(I,J),I=6,48)
      STOP
   10 FORMAT(5X,10I2)
   30 FORMAT(/10X,5HUNIT ,I2,1X,I2,8X,F6.1,3X,F6.1,4X,I1,2X,I1)
   31 FORMAT(/////10X,5HCAT A,I4,3X,5HCAT B,I4,3X,5HCAT C,I4,3X,5HCAT D,
     1I4,3X,5HCAT E,I4)
   32 FORMAT(/////4X,I6,5X,F4.1,8X,F4.1,8X,F4.1,8X,F4.1,8X,F4.1)
   33 FORMAT(/////10X,5HB 2UP,I4,3X,5HB 1UP,I4,3X,5HB = C,I4,3X,5HB 1DN,
     1I4,3X,5HB 2DN,I4)
   34 FORMAT(11X,43I2)
   40 FORMAT(/////1X,'DISPLAY OF WMMC AIR POLLUTION')
   41 FORMAT(/1X,'AIR POLLUTION PREDICTIONS FOR WMMC UNIT SQUARES')
   70 FORMAT(/////1X,'UNIT SQUARE PREDICTIONS USING B')
      END
      FINISH
```

This being so, and maintaining the grid-square configuration of the spatial data, the i zones which were considered, under the diffusion model, to contribute a significant degree of pollution to any given receptor zone (i=0), took the form of a set of 'nested' squares as illustrated in Fig. C.11. The figure shows the comparatively large 'catchment area' encompassed when N (see section 6.4.2) is put equal to 5 in accordance with the results of the calibration exercise. The relative importance of each of the i zones, signified by the values of the parameter k_i, is also discussed in section 6.4.1.

After calibration for the 36 receptor zones associated with the secondary-source National Survey sites, the urban diffusion model was applied to each of the 570 TAEs in the WMMC by means of a specially-written FORTRAN computer programme described in section 6.4.4. Table C.5 presents the computer listing of this programme; in operation the programme job description requirements were relatively modest, involving a job time of 120 seconds and a core size of 81k on the Aston University ICL 1904S computer.

C.4 ISSUES IN THE EMPIRICAL CALIBRATION OF THE URBAN DIFFUSION MODEL

The locations of the 36 National Survey sites and the 'receptor zones' for which the observed data were assumed to apply are shown in Fig. C.12. The observed winter mean concentrations themselves are presented in Table C.6. It wil be noted that these concentrations comprise a very sound coverage across the whole expected working range, this being 50-150 $\mu g\ m^{-3}$. The point is clearly demonstrated in Fig. C.13, which gives histograms of the sample frames of all the variables used in the empirical calibration exercise (the multiple regression analysis described in section 6.4.2 of the main text). As regards the independent variables it is seen that while in most instances the sample frames are adequate, the variables RC, RAX, RCX, CA and CB are less well covered. The implications of this fact are



Figures relate to the 'key' in Table C.6, which gives the National Survey site names and the mean SO_2 concentrations for 1975/6

Fig. C.12 Location of National Survey monitoring sites in the WMMC

Fig. C.13 'Sample frame' distributions for the dependent and independent variables.

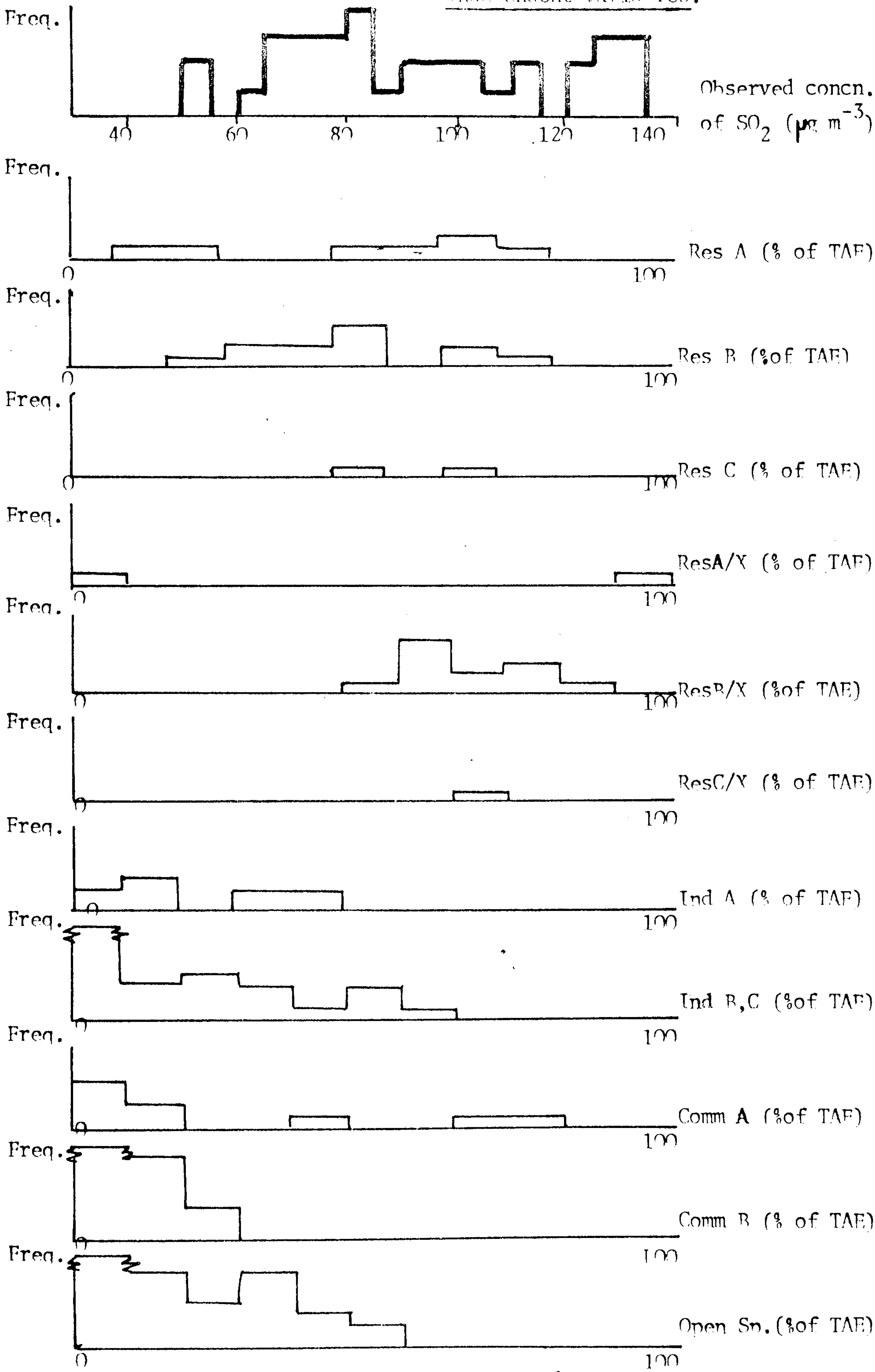


Table C.6 1975/6 Winter-mean Concentrations of Sulphur Dioxide Observed at the 36 National Survey Sites in the WMMC

Code No. in Fig. C.12	National Survey Site Name	Concentration (ug m^{-3})
1	Birmingham 20	142
2	Birmingham 21	124
3	Castle Bromwich 1	64
4	Brierley Hill 9	82
5	Coseley 1	82
6	Coventry 13	96
7	Darlaston 2/5	125
8	Darlaston 3	74
9	Halesowen 6	82
10	Halesowen 7	98
11	Oldbury 5	126
12	Oldbury 10	82
13	Rowley Regis 1	67
14	Sedgeley 1	70
15	Sedgeley 2/4	78
16	Smetwick 1	120
17	Smethwick 9	94
18	Solihull 3	71
19	Stourbridge 1	78
20	Sutton Coldfield 4	72
21	Sutton Coldfield 5	102
22	Sutton Coldfield 6	66
23	Tipton 11	100
24	Walsall 11	133
25	Walsall 13	87
26	Walsall 14/17	137
27	Walsall 15	108
28	Walsall 16	50
29	Wednesfield 1	76
30	West Bromwich 12	114
31	West Bromwich 16	111
32	West Bromwich 17	91
33	Willenhall 15	136
34	Wolverhampton 3	80
35	Wolverhampton 7	71
36	Wombourne 1/2	54

discussed at the beginning of section 6.4.3, where it is noted that the low significance of these same variables in the regression (see the relevant t-values in Table 6.5 in the main text) may be directly attributable to the poor sample frames. This inadequacy in the purely empirical method of determining the 'emission coefficients', q_u, was one of the prime factors leading to the introduction of a second stage in the calibration procedure involving a consideration of theoretical issues as described in section 6.4.3.

A further factor that might have constrained the reliability of the purely empirical approach concerns the presence of multicollinearity amongst the independent variables. Table C.7 gives the correlation matrix for the independent variables, which was derived as part of the process of the multiple regression analysis in the ICL XDS3 computer package. It is seen that the highest individual paired correlations (IA : RA and IA : CA) both give values of r^2 below 0.3, and in the majority of cases the correlations are very much lower. In view of this it was concluded that multicollinearity in the data set was not a major constraint upon the reliability of the empirical approach.

A final area where the empirical approach might be open to some criticism is in the relatively small number of 36 independent samples of data. For a regression analysis to be considered valid and reliable, SPRENT (1969) suggests that at least 30 independent samples are required for a simple regression, plus one for each additional variable when multiple regressions are considered, thus requiring 39 independent samples in the case of this research. However since the figures are very close, and Sprent's rule is only a guideline, it was held that the empirical regression analysis was not in itself invalid, although the reliability of the resulting coefficients could be open to some question. This latter point gave a further reason for considering modifications to the coefficients on the basis of certain theoretical guidelines.

As described in section 6.4.2 the main text, the initial empirical calibration of the model was conducted through multiple regression analysis. Ten different assumptions of B and N were taken and for each assumption a regression was performed; the chief regression parameters for these assumed values are given in Table C.8. It is seen that the assumed values

Table C.7 Correlation Matrix for the Variables in the Regression

	AP	RA	RB	RC	RAX	RBX	RCX	IA	IB	CA	CB	OS
AP	1.0	.09	.20	- .18	- .12	- .33	- .12	.45	.39	.35	.16	- .56
RA	.09	1.0	- .30	- .10	- .07	- .26	- .10	.49	- .30	.46	- .27	- .14
RB	.20	- .30	1.0	- .17	- .12	- .42	- .16	- .27	.50	- .22	.27	- .10
RC	- .18	- .10	- .17	1.0	- .04	- .15	- .06	- .10	- .03	- .08	.06	- .02
RAX	- .12	- .07	- .12	- .04	1.0	- .10	- .04	- .07	- .12	- .05	- .10	- .17
RBX	- .33	- .26	- .42	- .15	- .10	1.0	- .15	- .26	- .24	- .20	- .06	.27
RCX	- .12	- .10	- .16	- .06	- .04	- .15	1.0	- .10	- .17	- .08	- .15	.03
IA	.45	.49	- .29	- .10	- .07	- .26	- .10	1.0	- .29	.55	- .26	- .37
IB	.39	- .30	.50	- .03	- .12	- .24	- .17	- .29	1.0	- .22	- .34	- .35
CA	.35	.46	- .22	- .08	- .05	- .20	- .08	.55	- .22	1.0	- .20	- .31
CB	.16	- .27	.27	.06	- .10	- .06	- .15	- .26	.34	- .20	1.0	- .48
OS	- .56	- .14	- .10	.02	- .17	.27	.03	- .37	- .35	- .31	- .48	1.0

N.B. AP: Observed air pollution concentration (i.e. the dependent variable)

Table C.8 Regression Parameters r, r.e., and G for Ten Different Assumptions of B and N

N Value \ B Value	B = 0.18			B = 0.25			B = 0.30		
	r	r.e.	G	r	r.e.	G	r	r.e.	G
N = 0							.762	18.7	51.5
1	-	-	-	.752	19.2	67.3	.783	18.1	49.4
3	.790	17.8	44.4	.793	17.8	45.3	.794	17.7	39.4
5	.798	17.6	44.2	.796	17.6	44.0	.809	17.1	35.4

Key r - multiple correlation coefficient

r.e. - residual error ($\mu g\ m^{-3}$)

G = regression constant ($\mu g\ m^{-3}$)

- = no regression analysis performed

N.B. Parameters achieved for 99% significance level

B = 0.30, N = 5 allow the highest correlation with the dependent variable to be achieved and therefore these values, and the corresponding values of q_u and G, were taken to comprise the best empirical calibration of the model. This empirical model was then modified with respect to various theoretical criteria through the 'iterative apportionment' method described in section 6.4.3.

The model which finally resulted showed a residual error, r.e., of 15.5 $\mu g\ m^{-3}$. This value was used in standard formulae to obtain the 95% confidence intervals for the model, as shown in Fig. 6.5 in the main text. Because the analysis of the model's accuracy was obtained by the simple regression of observed concentrations (as the dependent variable) against the predicted concentrations (as the independent variable), it was possible to use the formulae for simple regression confidence intervals (e.g. HUANG 1970, SPRENT 1969).

Two types of confidence interval may be derived: the first described as the confidence in predicting a particular observation Y given the condition of the 'observed' independent variable X; the second describes the confidence in predicting the mean of all observations Y that occur for a given particular value of X. Naturally the confidence intervals in the latter case are smaller (i.e. greater accuracy is evident) than in the former.[1] The interpretation of these two types of confidence interval as applied to the urban diffusion model is given in section 6.4.5. If the two types of confidence interval are termed C_1 and C_2 respectively, then their values may be calculated from the relations:

$$C_1 = \pm t_{100-\alpha,\ N-2}\ \hat{\sigma} \sqrt{1 + n + \frac{(x_i - \bar{x})^2}{\sum_i (x_i - \bar{x})^2}}$$

Eqn. C.1

$$C_2 = \pm t_{100-\alpha,\ N-2}\ \hat{\sigma} \sqrt{n + \frac{(x_i - \bar{x})^2}{\sum_i (x_i - \bar{x})^2}}$$

Eqn. C.2

where $\hat{\sigma}$ = r.e.; thus the 95% confidence intervals are given using $t_{95,34}$, i.e. the significant t-value at 95% confidence for 34 degrees of freedom, with n = 36. Table C.9 shows the resulting data from which the confidence intervals were drawn; a range of values of x_i (i.e. predicted sulphur dioxide concentrations) was chosen as shown, and for each value the two types of 95% confidence level were calculated using equations C.1 and C.2 with $\hat{\sigma} = 15.5\ \mu g\ m^{-3}$, $t_{95,34} = 2.04$, and $\bar{x} = 92.6\ \mu g\ m^{-3}$ for the data set upon which the regression was performed. The range of x_i values was chosen to cover the working range of the model, and so the curves in Fig. 6.5, drawn freehand from the data in Table C.8, correspond to this working range.

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1. As in all statistical analysis, the mean can be predicted with greater accuracy than an individual item or event.

Table C.9 95% Confidence Intervals for a Range of Predicted (Independent Variable) Concentrations ($\mu g\ m^{-3}$)

Predicted Concentration Values	42.6	52.6	62.6	72.6	82.6	92.6	102.6	112.6	122.6	132.6	142.6
Confidence for a particular TAE	±34.8	±33.9	±33.1	±32.5	±32.1	±32.0	±32.1	±32.5	±33.1	±33.9	±34.8
Confidence for mean of all TAEs with given independent variable values	±14.8	±12.3	± 9.9	± 7.6	± 6.0	± 5.3	± 6.0	± 7.6	± 9.9	±12.3	±14.8

APPENDIX D

MONOGRAPHS OF THE NINETEEN TAE TYPES

This appendix presents a set of illustrated monographs describing the urban fabric characteristics and environmental conditions associated with each of the nineteen TAE types defined in the thesis (Chapter 4.3). For each TAE type the environmental conditions predicted by the TAE prediction models for ambient noise, sulphur dioxide, area appearance and aggregate environmental conditions are summarised, a physical description of the urban fabric characteristics is given, and a map is presented showing locations of the TAEs of that given type within the WMMC. The maps should be compared with the general land use map (Fig. A.2) to give orientation with respect to the principal towns and cities. Two photographs showing typical or illustrative aspects of each TAE type are also presented.

The purpose of these monographs is to show the distinctive nature of the categories that were defined somewhat academically through the TAE typology as discussed in Chapter 4.3, to show the comprehensive coverage of the typology, and to allow a greater understanding of and qualitative feel for the area types whose environmental conditions are predicted and mapped through the TAE methodology described in the thesis.

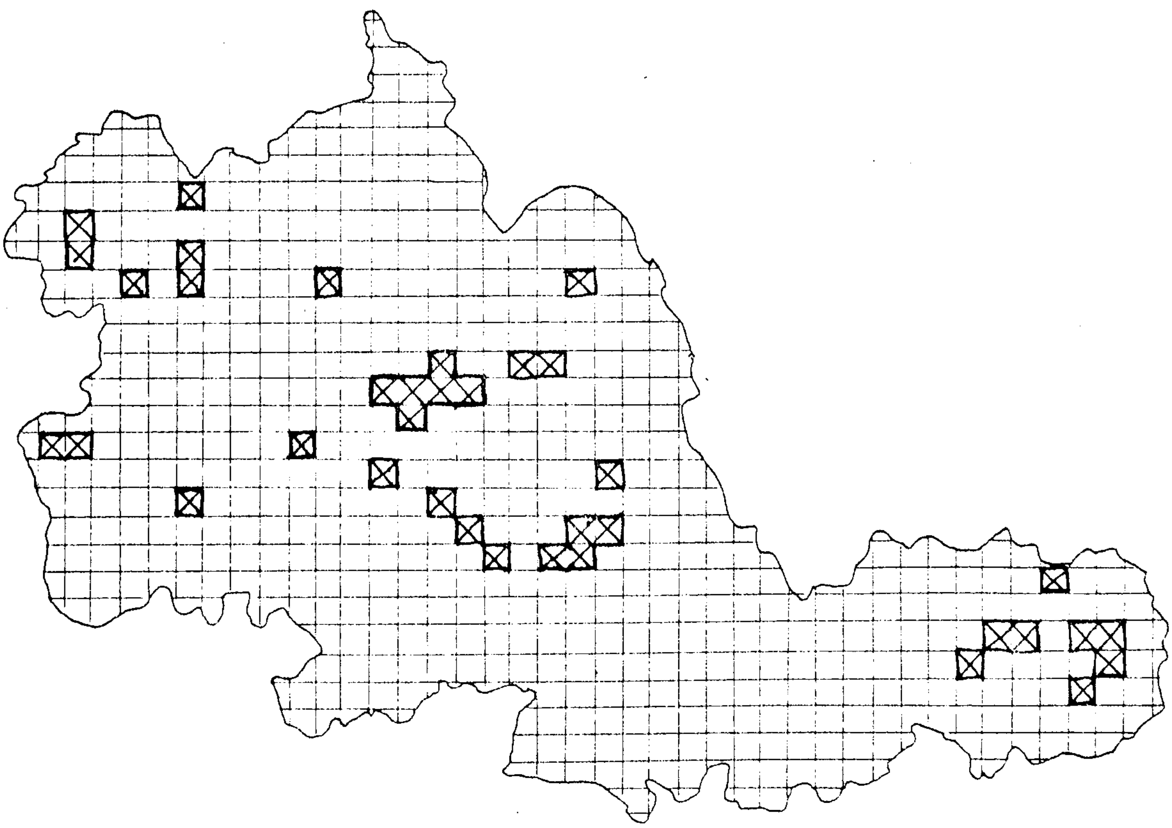
The monographs follow the same sequence of area types as the TAE prediction model matrices.

TAE TYPE OA: RESIDENTIAL, DENSE ROAD NETWORK

Environmental predictions

DATA TYPE	AMBIENT NOISE L_{10}, L_{90}, L_{eq} (dBA)	SULPHUR DIOXIDE ($\mu g\ m^{-3}$)	AREA APPEARANCE (Score)	AGGREGATE CONDITIONS (Rank)
Mean conds	59.6 48.6 55.8	90	5	-
Rank	10	11	9	9
TAE group	3	3	3	3

General description Predominantly the older inner-city residential areas, often Victorian terraced housing with poor area appearance, or larger Victorian houses now converted to private-rented multiple occupancy flats. The map shows the inner core 'rings' of such areas around Birmingham, Wolverhampton and Coventry. Residential densities are high and in most cases the socio-economic status of the residents is low. Environmental conditions are not generally as poor as in the areas where there is also a mix of industry (e.g. Type 4A).



Map showing the distribution of TAEs of type OA in the WMMC

Total no. of OA type TAEs = 35 Proportion of land area =6.1%

Typical inner-city Victorian working class terraced housing in Pleck, Walsall. Houses are of the 'two up, two down' type, fronting directly onto pavements devoid of front gardens or trees.

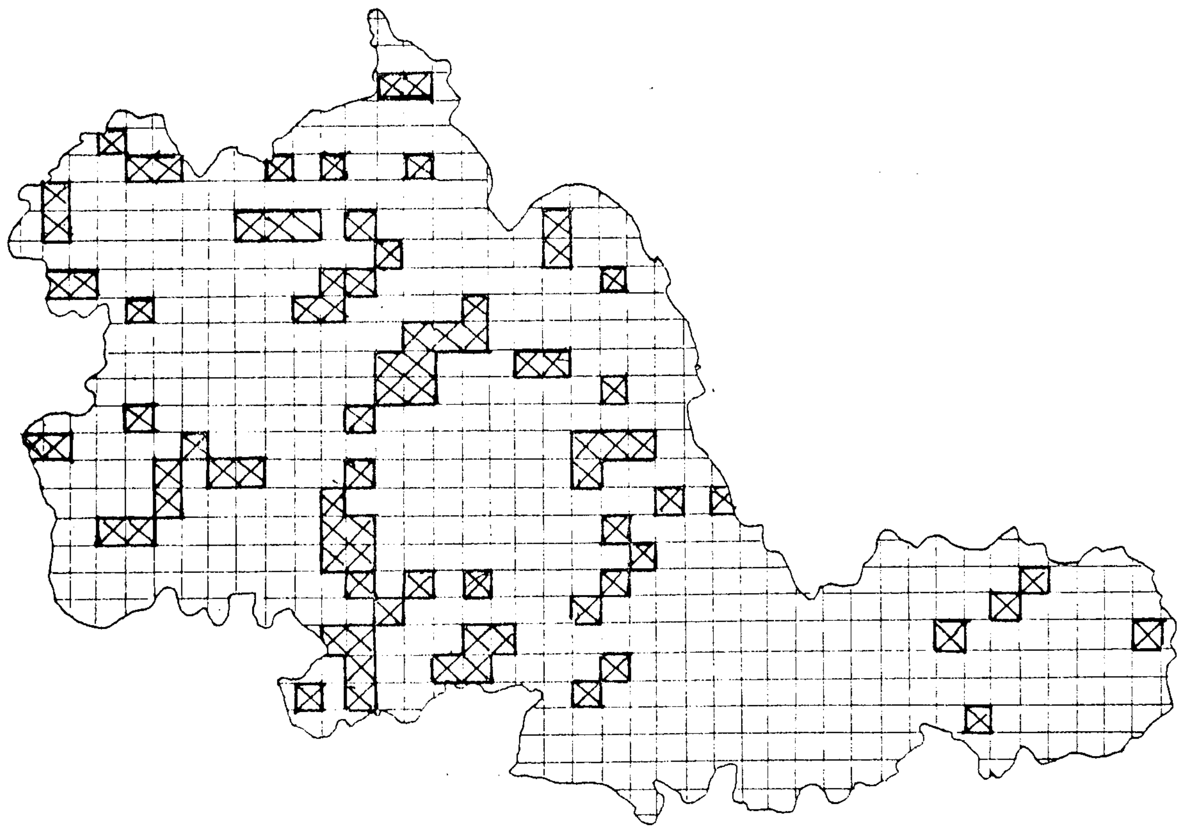
Larger, three-storey Victorian housing in Wolverhampton. Trees are often found at the streetside; houses frequently converted into 'bedsitter-land'.

TAE TYPE OB: RESIDENTIAL, MEDIUM NETWORK DENSITY

Environmental predictions

DATA TYPE	AMBIENT NOISE L_{10}, L_{90}, L_{eq} (dBA)	SULPHUR DIOXIDE ($\mu g\ m^{-3}$)	AREA APPEARANCE (Score)	AGGREGATE CONDITIONS (Rank)
Mean conds	56.5 45.7 53.0	91	7	-
Rank	14	10	13	14
TAE group	4	3	4	4

General description Often inter-war estates, including large Council-rented developments but also substantial owner-occupied areas. Houses generally of the semi-detached or linked-residence types. The map shows the zones of such areas encircling the larger cities, of which Birmingham is the most prominent example. The socio-economic status of residents is fairly mixed with the emphasis upon young families. Residential densities are lower and environmental conditions better than in OA-type areas.



Map showing the distribution of type OB areas in the WMMC

Total no. of OB type areas = 51   Proportion of WMMC land area = 8.9%

Inter-war Council housing in Perry Barr, Birmingham

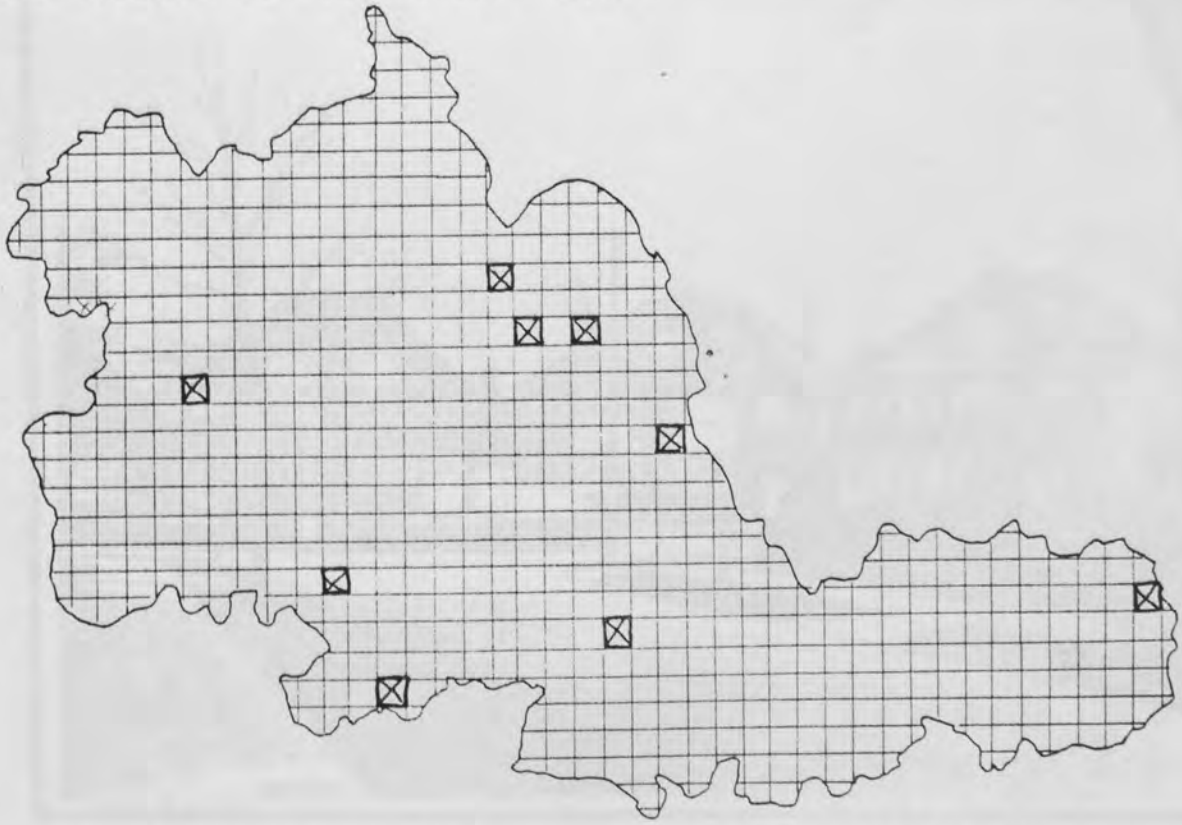
Semi-detached Council housing in Stechford, Birmingham; part of an extensive estate.

TAE TYPE OC: RESIDENTIAL, SPARSE ROAD NETWORK

Environmental predictions

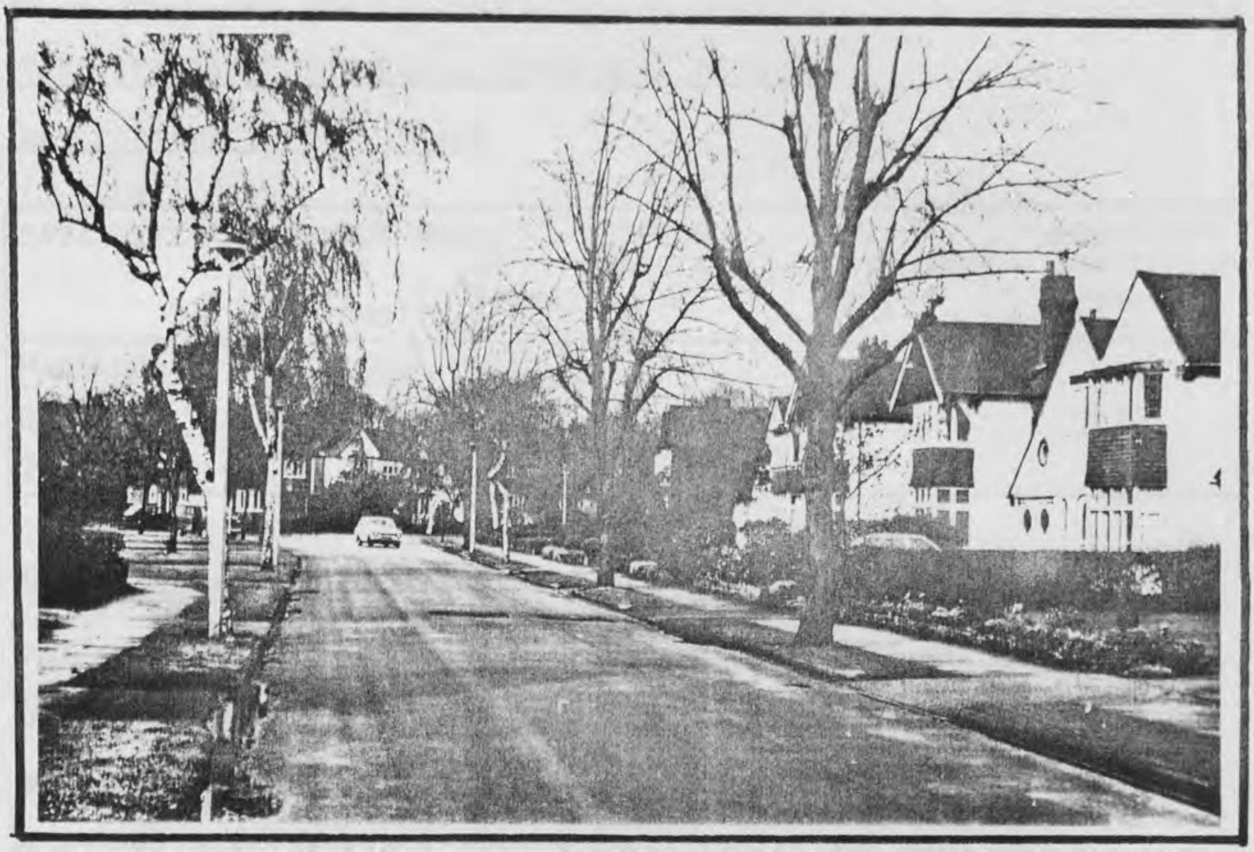
DATA TYPE	AMBIENT NOISE L_{10}, L_{90}, L_{eq} (dBA)	SULPHUR DIOXIDE ($\mu g\ m^{-3}$)	AREA APPEARANCE (Score)	AGGREGATE CONDITIONS (Rank)
Mean conds	53.3 43.1 49.6	75	8	-
Rank	17	17	18	18
TAE group	4	4	5	5

General description Residential areas in the outer parts of urban areas; large detached or semi-detached houses under owner-occupation. The map shows the location of such areas, mainly around the outer periphery of Birmingham (the widening 'ring-pattern' of types OA, OB and OC around Birmingham city is a notable feature shown by this and the preceding maps). Socio-economic status of residents is high and environmental conditions are good. Residential densities are low, with most houses possessing substantial gardens; roads are of the 'avenue' or 'cul-de-sac' types.



Map showing the distribution of type OC areas in the WMMC

Total no. of OC type TAEs = 13 Proportion of WMMC land area = 2.3%



Spacious avenue of owner-occupied detached houses in Boldmere,
Sutton Coldfield.

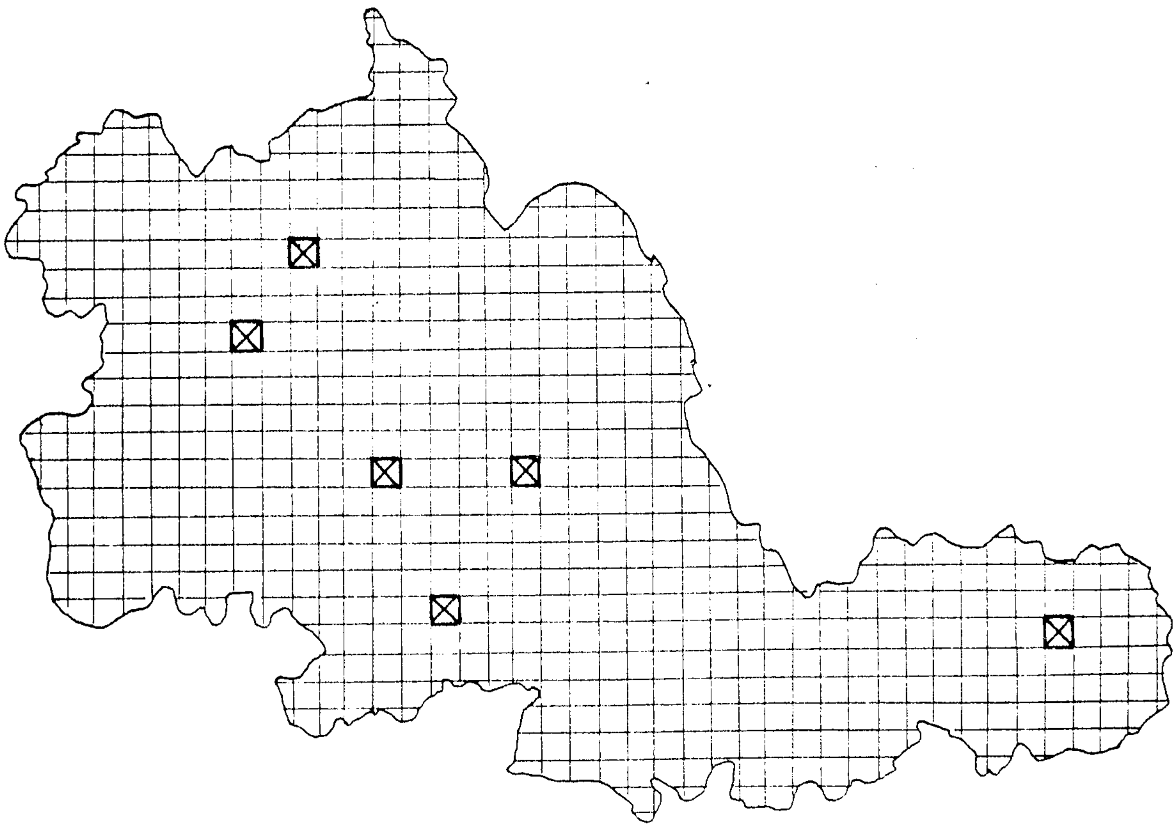
Large semi-detached houses in a cul-de-sac in outer Yardley,
Birmingham.

TAE TYPE 1A: INDUSTRIAL, DENSE ROAD NETWORK

Environmental predictions

DATA TYPE	AMBIENT NOISE L_{10}, L_{90}, L_{eq} (dBA)	SULPHUR DIOXIDE ($\mu g\ m^{-3}$)	AREA APPEARANCE (Score)	AGGREGATE CONDITIONS (Rank)
Mean conds	62.6 54.1 59.4	126	4	-
Rank	7	2=	8	6
TAE group	2	1	2	2

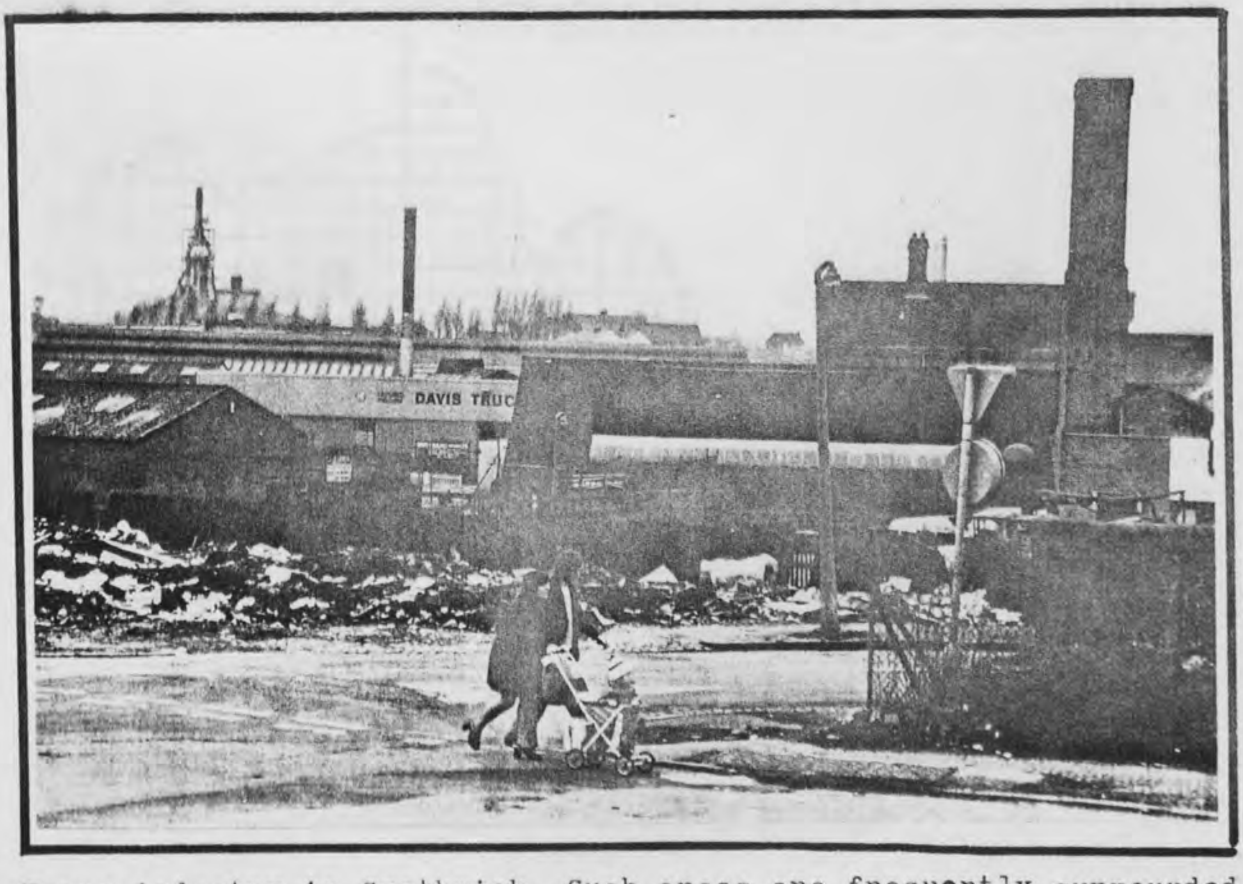
General description Industrial centres, usually close to city centres. Industrial buildings are often old and small, lining dense networks of inner-city roads, and environmental conditions are generally rather poor. Air pollution is especially severe, particularly where older industrial buildings are concerned. Small metal-based industries are common.



Map showing the distribution of 1A type areas in the WMMC

Total no. of 1A type TAEs = 6 Proportion of WMMC land area = 1.1%

Densely-packed, Victorian inner-city industrial buildings in Walsall. Buildings frequently obsolete and in decay.



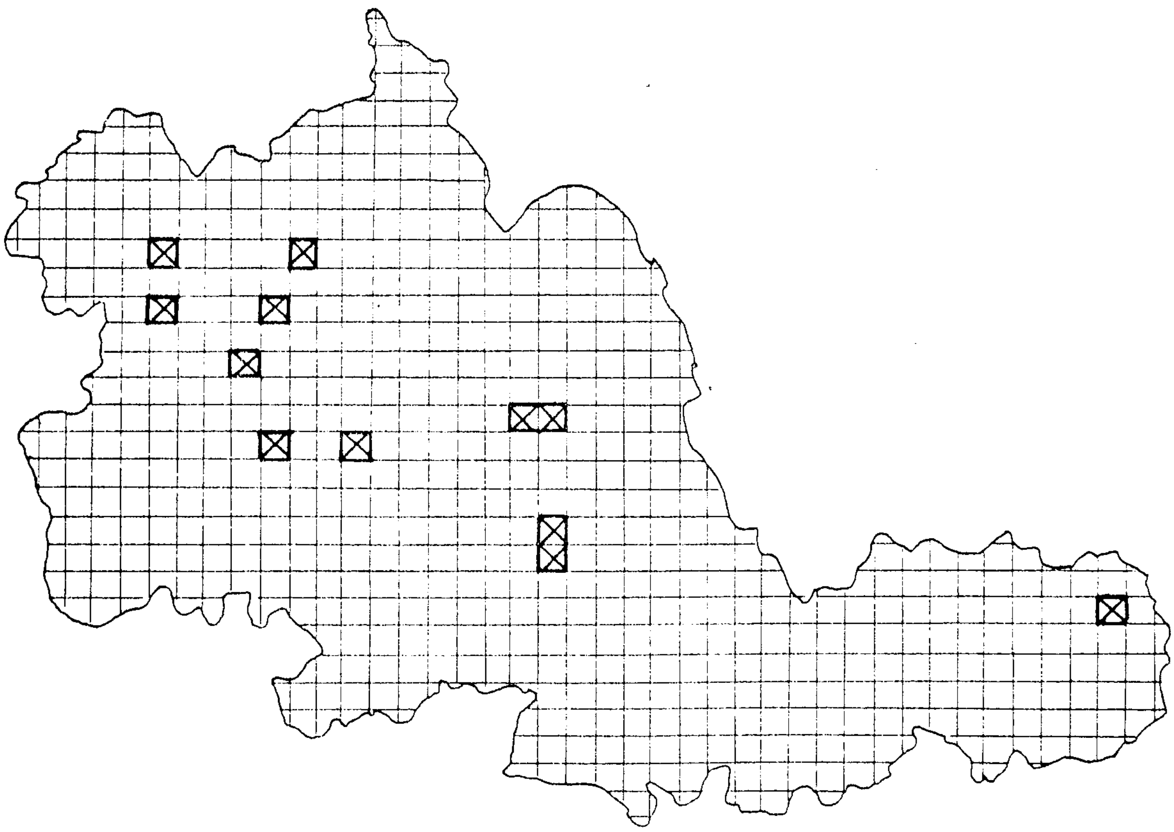
Heavy industry in Smethwick. Such areas are frequently surrounded by inner-city housing in adjacent areas, exposing families to high pollution levels.

TAE TYPE 1B: INDUSTRIAL, MEDIUM ROAD NETWORK

Environmental predictions

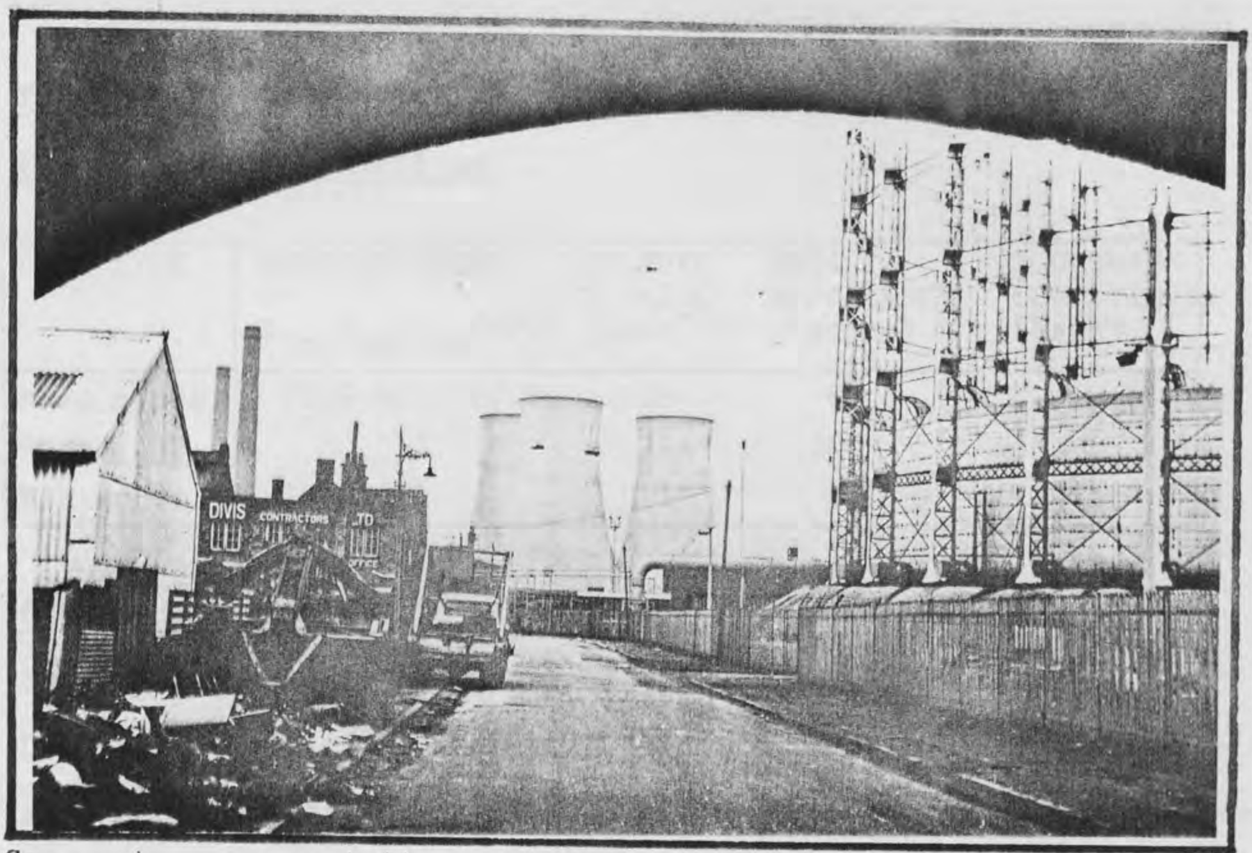
DATA TYPE	AMBIENT NOISE L_{10}, L_{90}, L_{eq} (dBA)	SULPHUR DIOXIDE ($\mu g\ m^{-3}$)	AREA APPEARANCE (Score)	AGGREGATE CONDITIONS (Rank)
Mean conds	63.1 56.6 60.6	114	3	-
Rank	6	5	6	5
TAE group	2	2	2	2

General description Industrial heartlands, often some 3-4km from the nearest city or town centre. Where not occupied by industrial buildings, land is often derelict or vacant. Predominance of heavy industry, e.g. steelworks, foundries and heavy engineering. Environmental conditions are generally poor, but exposure is low owing to the lack of neighbouring residential areas.

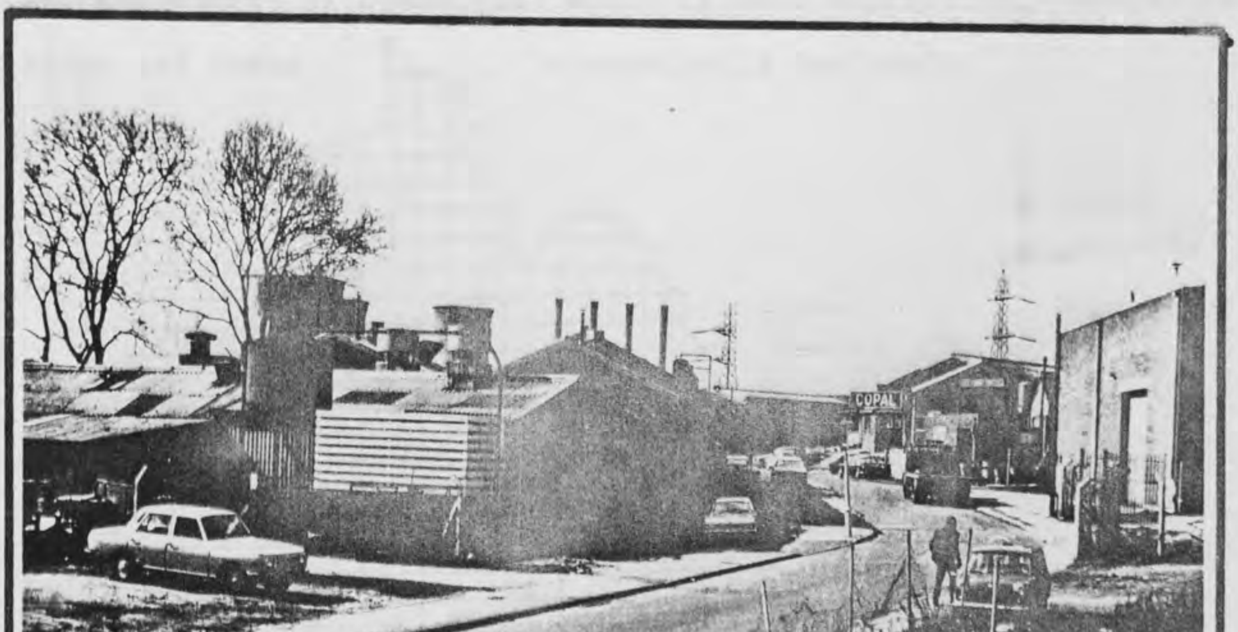


Map showing the distribution of 1B type areas in the WMMC

Total no. of 1B type TAEs = 12 Proportion of WMMC land area = 2.1%



Gas works, power station and scrap metal salvage works seen from beneath a railway arch in Saltley, Birmingham.



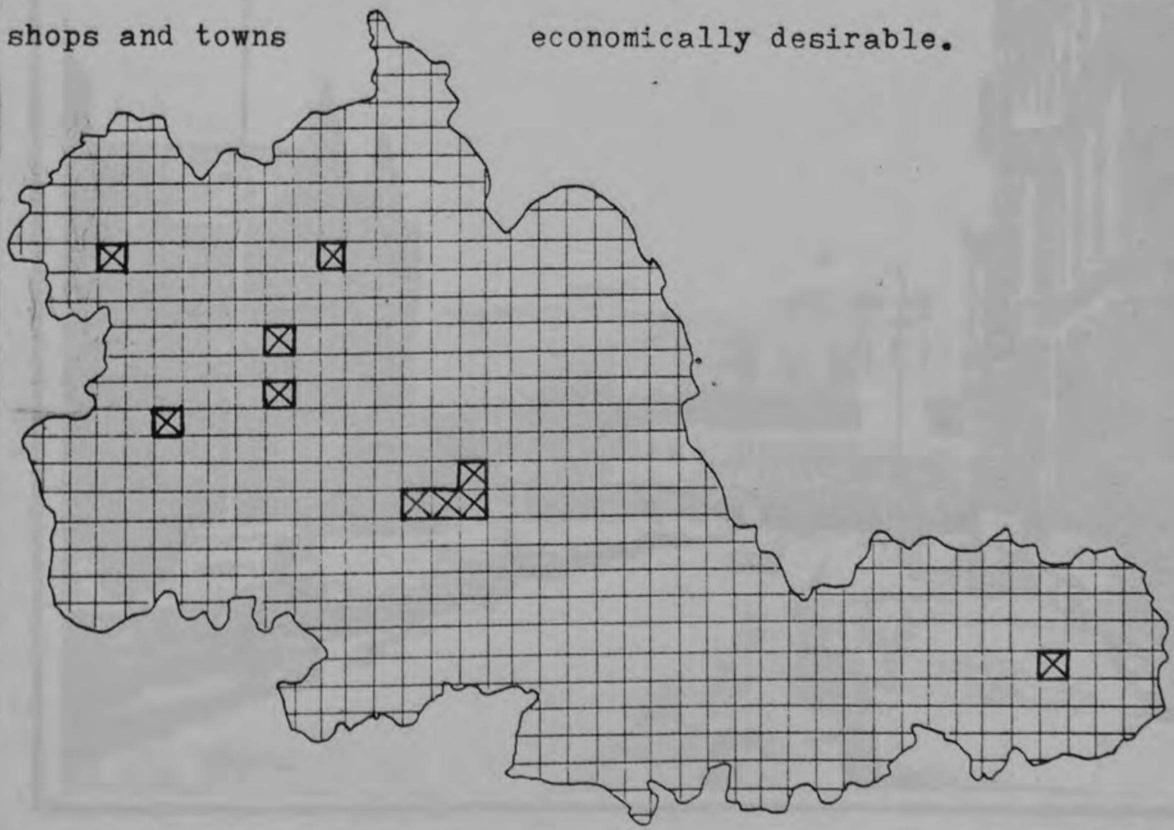
Engineering industries in the Black Country (Great Bridge, West Bromwich). Note the plots of waste land.

TAE TYPE 2A: COMMERCIAL, DENSE ROAD NETWORK

Environmental predictions

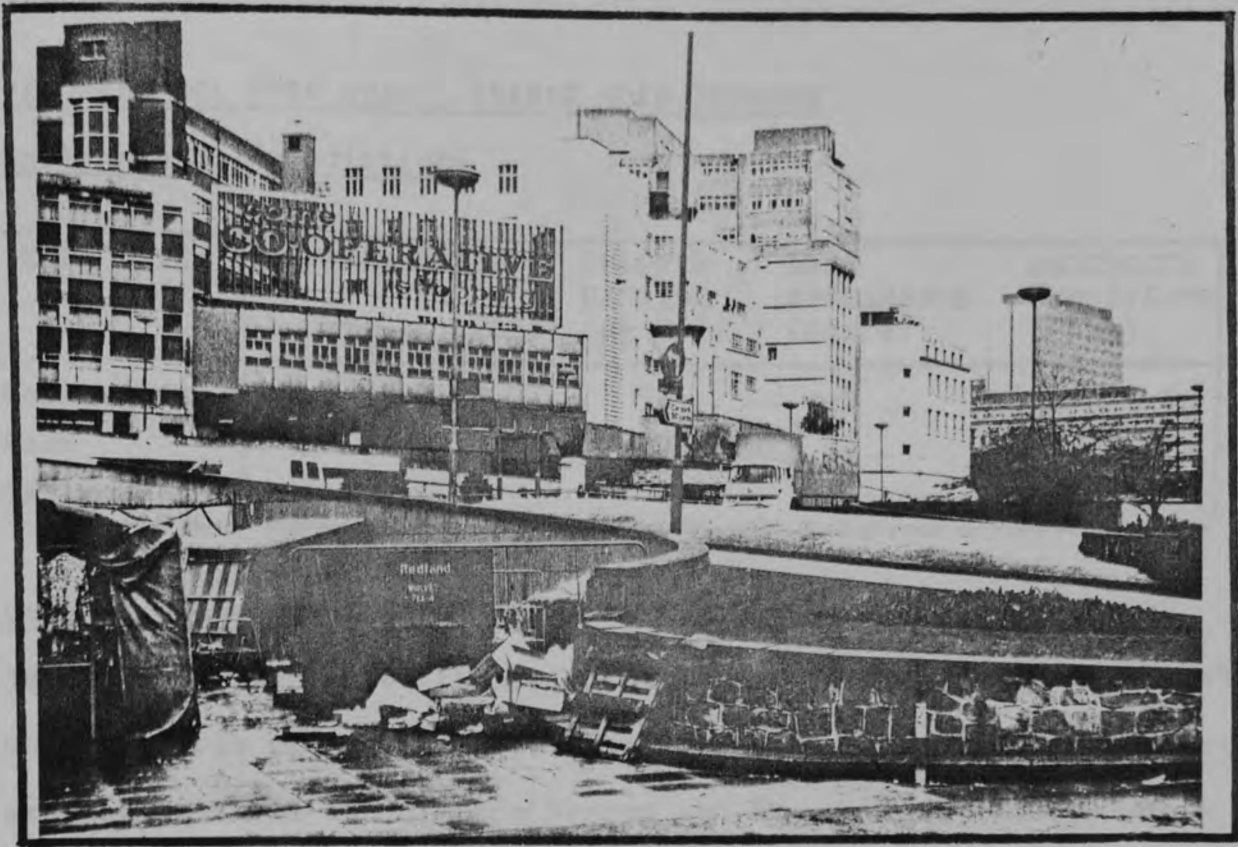
DATA TYPE	AMBIENT NOISE L_{10}, L_{90}, L_{eq} (dBA)	SULPHUR DIOXIDE ($\mu g\ m^{-3}$)	AREA APPEARANCE (Score)	AGGREGATE CONDITIONS (Rank)
Mean conds	70.6 62.7 67.7	126	6	-
Rank	1 - -	2=	10	4
TAE group	1	1	3	1

General description The main urban city centres; the map shows Birmingham, Coventry, Wolverhampton, Walsall, West Bromwich and Dudley. Activities include mass retail centres, public administration and business. Noise levels are exceptionally high mainly due to heavy traffic flow on almost all roads. Air pollution is high, due particularly to office and retail store space-heating systems. Area appearance is often more acceptable however, because property prices and the degree of commercial activity make attractively-maintained shops and towns economically desirable.



Map showing the distribution of 2A type areas in the WMMC

Total no. of 2A type TAEs = 10 Proportion of WMMC land area = 1.8%



The commercial centre of Birmingham seen from the Bull Ring market.

Public buildings in the city centre: police station (left), general hospital(right), fire station (middle distance), and Birmingham Polytechnic and Aston University(far distance); Steelhouse Lane,B'hm.

TAE TYPE 3C: OPEN SPACE, SPARSE ROAD NETWORK

Environmental predictions

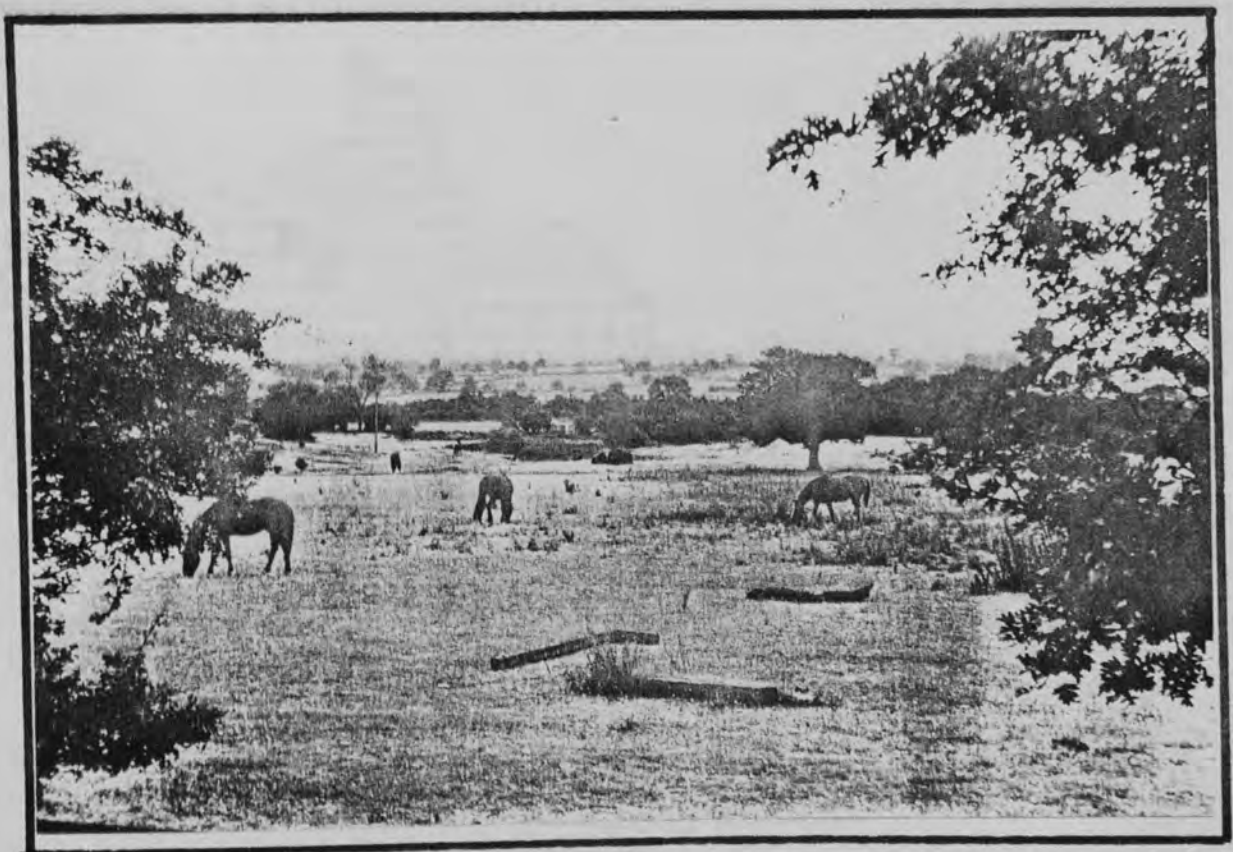
DATA TYPE	AMBIENT NOISE L_{10}, L_{90}, L_{eq} (dBA)	SULPHUR DIOXIDE ($\mu g\ m^{-3}$)	AREA APPEARANCE (Score)	AGGREGATE CONDITIONS (Rank)
Mean conds	46.3 39.7 43.7	54	9	-
Rank	19	19	19	19
TAE group	5	5	5	5

General description Rural areas at some distance from any urban land use The map shows the solid belt of agricultural land separating Coventry from the remainder of the Conurbation, and the recreational and agricultural lan of Barr Beacon and the Sandwell Valley which forms a wedge between Birmingham, and the Black Country to the West. Environmental conditions are very good; for each attribute discussed in this thesis, type 3C is the least polluted of all the TAE types.

Map showing the distribution of type 3C areas in the WMMC

Total no. of 3C type TAEs = 131 Proportion of WMMC land area = 23.0%

Typical English country lane in an agricultural area; Barston, Solihull.



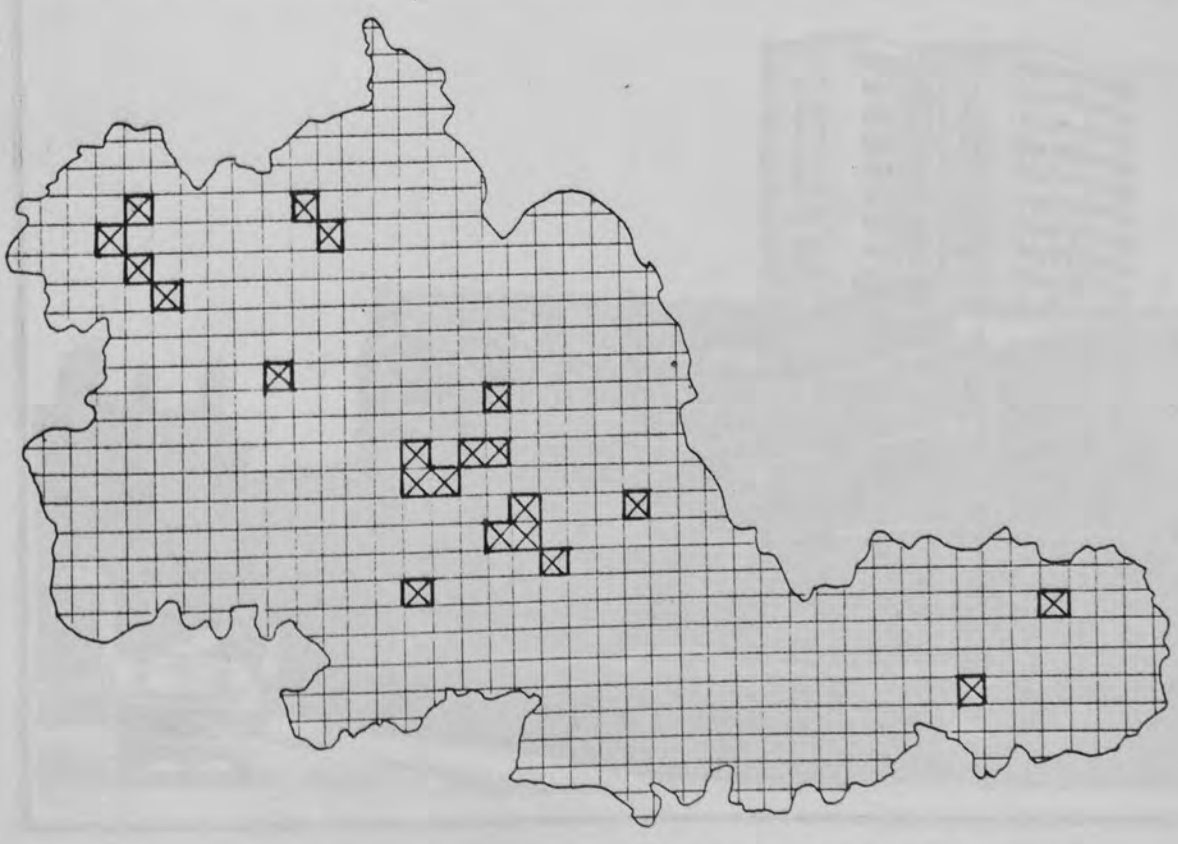
Semi-rural recreational area; riding centre paddock on the Western slopes of Barr Beacon.

TAE TYPE 4A: RESIDENTIAL/INDUSTRIAL MIX, DENSE ROAD NETWORK

Environmental predictions

DATA TYPE	AMBIENT NOISE L_{10}, L_{90}, L_{eq} (dBA)	SULPHUR DIOXIDE ($\mu g\ m^{-3}$)	AREA APPEARANCE (Score)	AGGREGATE CONDITIONS (rank)
Mean conds	65.1 56.1 61.9	115	2	-
Rank	4	4	2=	3
TAE group	2	2	1	1

General description Inner core areas dominated by Victorian terraced housing and industrial buildings. Redeveloped areas sometimes contain modern Council tower-blocks; otherwise housing type is similar to type OA but without the larger Victorian houses, and areas are closer to the major city centres (e.g. Birmingham, see map) than are the OA type areas. Environmental conditions are generally poor; area appearance is particularly bad. Exposure is high due to the high residential density.



Map showing the distribution of type 4A areas in the WMMC

Total no. of 4A type TAEs = 20 Proportion of WMMC land area = 3.5%

Typical Victorian urban industrial structure: workers' housing with factory at the end of the street. Balsall Heath, Birmingham.

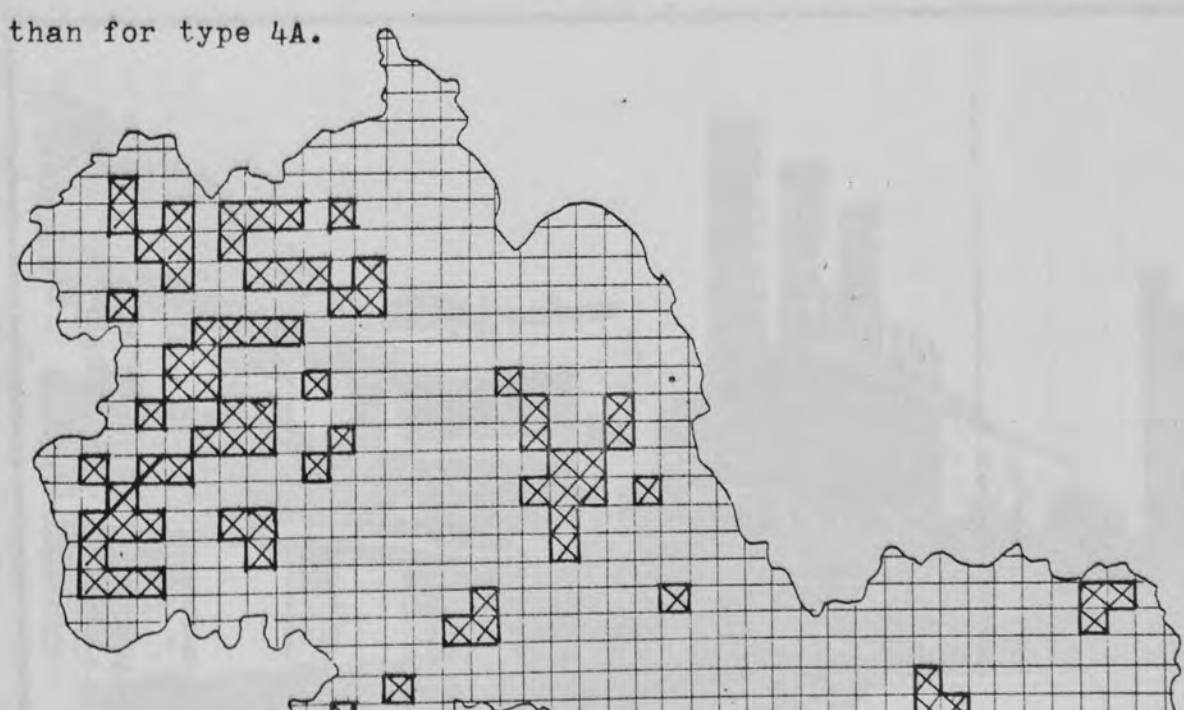
Modern Council tower-blocks overlook inner-city industrial buildings in Smethwick.

TAE TYPE 4B: RESIDENTIAL/INDUSTRIAL MIX, MEDIUM NETWORK DENSITY

Environmental predictions

DATA TYPE	AMBIENT NOISE L_{10}, L_{90}, Leq	SULPHUR DIOXIDE ($\mu g\ m^{-3}$)	AREA APPEARANCE (Score)	AGGREGATE CONDITIONS (Rank)
Mean conds	61.8 54.9 60.4	103	4	-
Rank	8 - -	7	7	7
TAE group	2	2	2	2

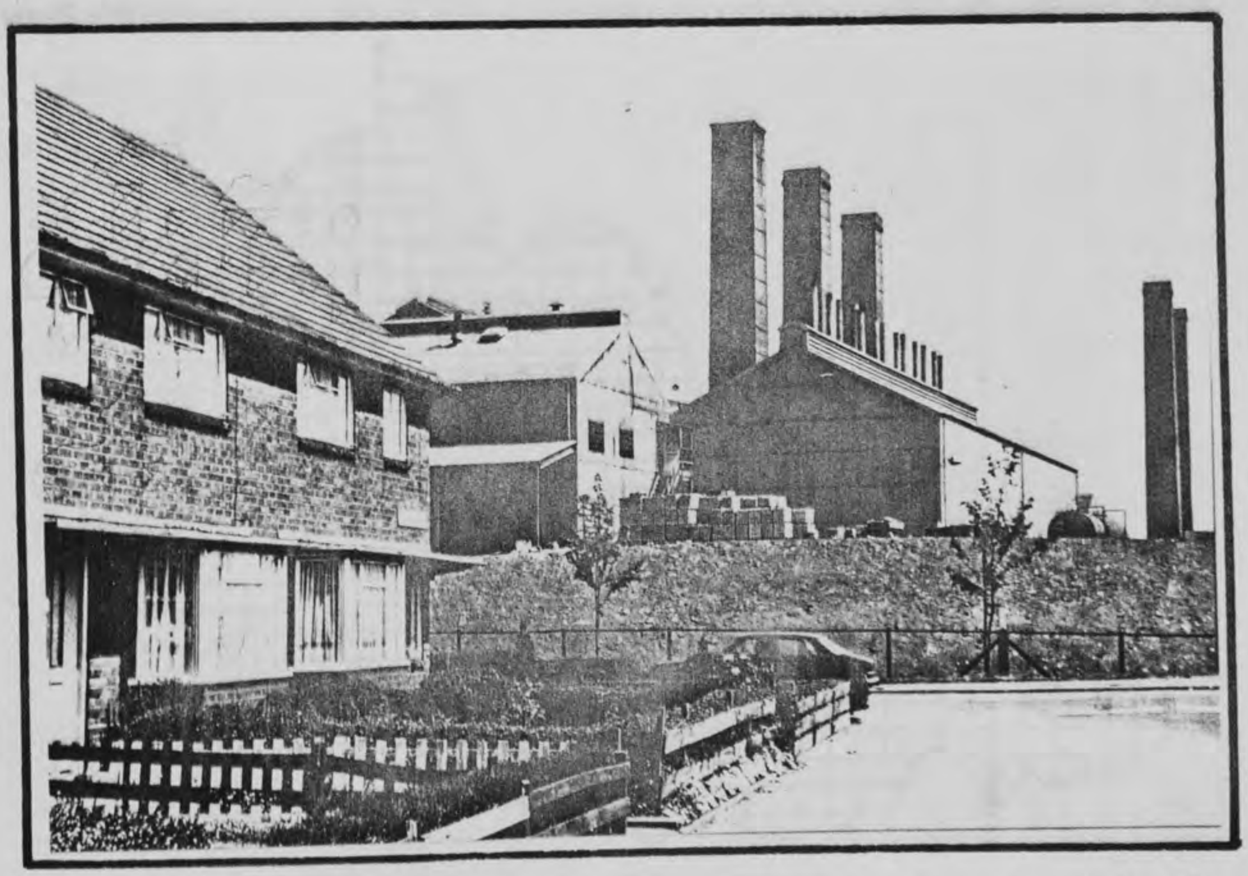
General description This area type dominates the Black Country, as seen from the map, and is also quite common in the Birmingham area. Typically, groups of linked or semi-detached residences of the inter-war period, or older terraces, are interspersed with relatively small manufacturing plants. Often the houses back onto industry. The socio-economic status of residents is generally rather low, houses may be Council-owned or owner-occupied. Environmental conditions are on the whole rather poor, but better than for type 4A.



Map showing the distribution of type 4B areas in the WMMC

Total no. of 4B type TAEs = 51 Proportion of WMMC area =8.9%

Houses backing onto industrial plant in Willenhall, Black Country.



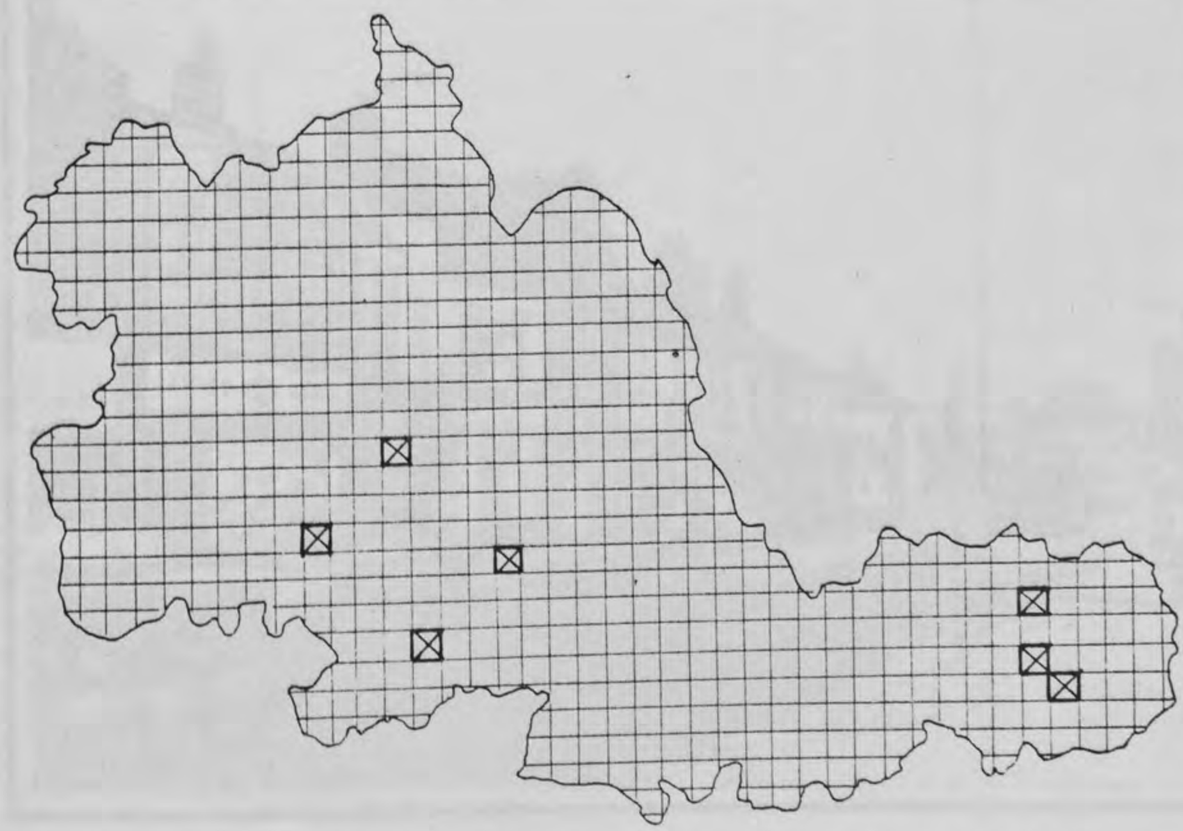
Residential and industrial zones juxtaposed in Leamore, Walsall.

TAE TYPE 5A: RESIDENTIAL/COMMERCIAL MIX, DENSE ROAD NETWORK

Environmental predictions

DATA TYPE	AMBIENT NOISE L_{10}, L_{90}, L_{eq} (dBA)	SULPHUR DIOXIDE ($\mu g\ m^{-3}$)	AREA APPEARANCE (Score)	AGGREGATE CONDITIONS (Rank)
Mean conds	57.4 50.4 54.7	97	7	-
Rank	13	8	12	11
TAE group	3 - -	3	3	3

General description Shopping streets in the older urban areas. Shopping centres are frequently linearly distributed along the older trunk roads (e.g. Stratford Road, Birmingham). Many of the shops are small, Victorian or early twentieth-century buildings and are becoming abandoned as local residents travel further to buy more cheaply at the supermarkets found in larger centres. Environmental conditions are similar to those in OA type areas.



Map showing the distribution of 5A type areas in the WMMC

Total no. of 5A type TAEs = 7 Proportion of WMMC area = 1.2%

Typical example of inner urban shopping street surrounded by Victorian terraced housing; Deritend, Birmingham.

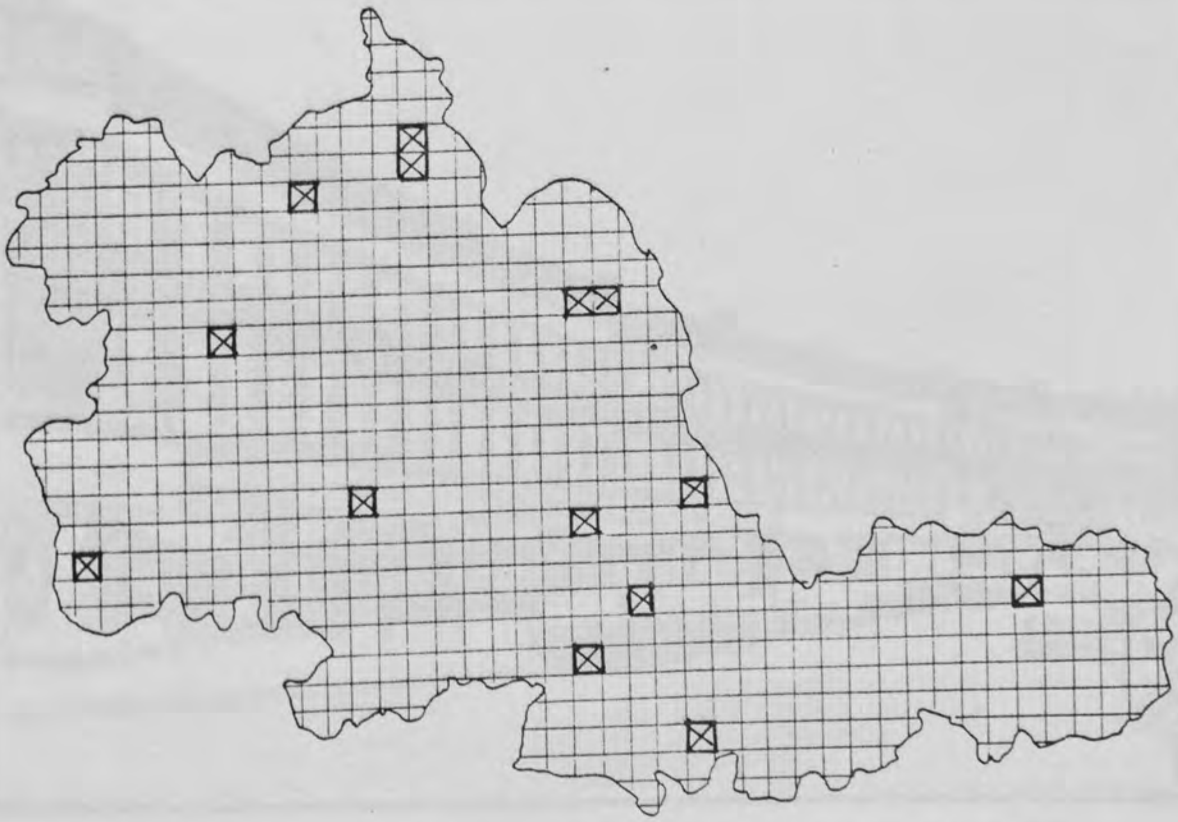
West Smethwick High Street: an example of inner urban decay due to demolition and depopulation of surrounding terraced streets. 80% of shops abandoned.

TAE TYPE 5B: RESIDENTIAL/COMMERCIAL MIX, MEDIUM NETWORK DENSITY

Environmental predictions

DATA TYPE	AMBIENT NOISE L_{10}, L_{90}, L_{eq} (dBA)			SULPHUR DIOXIDE ($\mu g\ m^{-3}$)	AREA APPEARANCE (Score)	AGGREGATE CONDITIONS (Rank)
Mean conds	58.4	47.5	54.9	95	5	-
Rank	12	-	-	9	11	10
TAE group	3			3	3	3

General description Suburban shopping centres; the map shows these areas distributed fairly evenly throughout the County. The shopping centres are often purpose-built, with parking provision, etc. not usually found in the 5A type centres. Residential land is commonly of the owner-occupied semi-detached type, with the socio-economic status of residents noticably higher than in 5A type areas. Environmental conditions are generally similar to those in 5B type areas.



Map showing the distribution of type 5B areas in the WMMC

Total no. of 5B type TAEs = 11 Proportion of WMMC area = 1.9%

Affluent suburban shopping precinct in Solihull town centre.

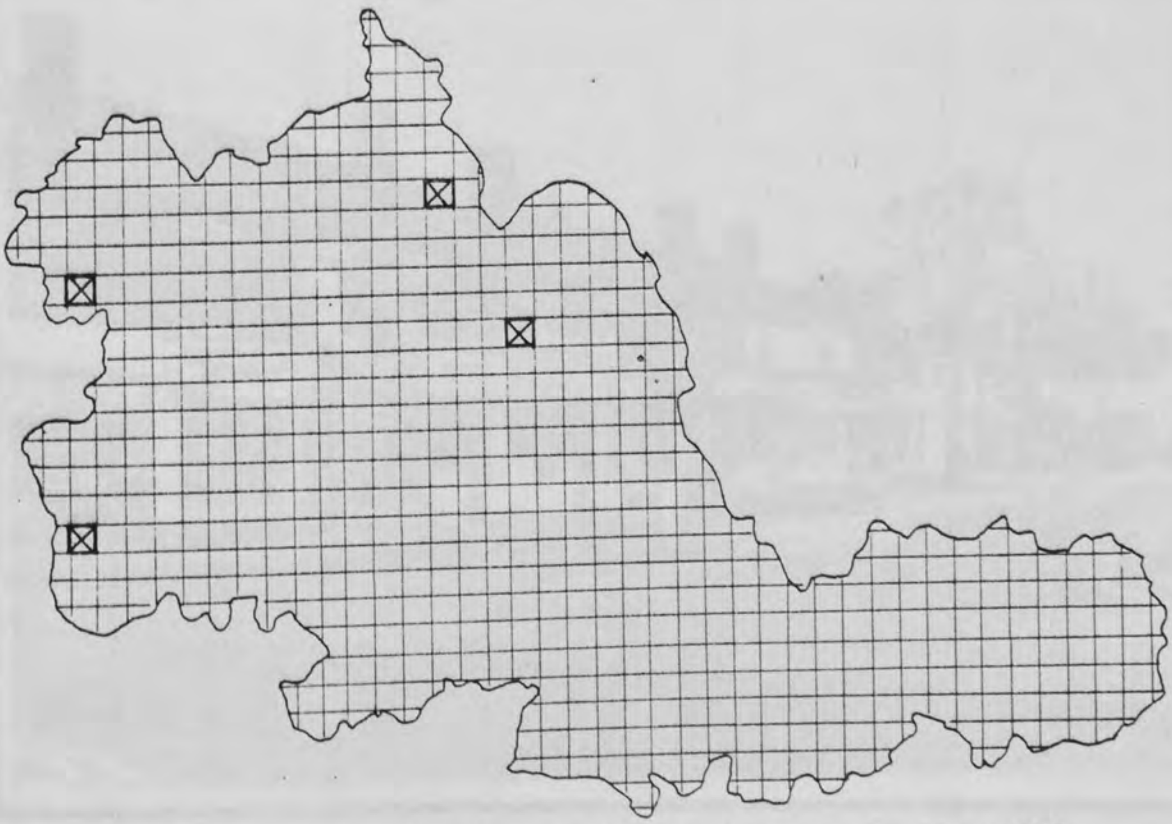
Jubilee Crescent, Coventry; a typical suburban shopping centre in a residential area of mixed Council and owner-occupied semi-detached housing.

TAE TYPE 5C: RESIDENTIAL/COMMERCIAL MIX, SPARSE ROAD NETWORK

Environmental predictions

DATA TYPE	AMBIENT NOISE L_{10}, L_{90}, L_{eq} (dBA)			SULPHUR DIOXIDE ($\mu g\ m^{-3}$)	AREA APPEARANCE (Score)	AGGREGATE CONDITIONS (Rank)
Mean conds	60.2	51.9	57.1	79	8	-
Rank	9	-	-	13	14=	13
TAE group	3			4	4	4

General description An uncommon area type, found on the fringes of the Conurbation. Small groups of shops in low-density residential areas, often also accompanied by a noticable amount of public open space. Some centres are associated with the older mining villages in the Black Country, and in othe cases shops are found interspersed within more modern, post-war housing areas. Environmental conditions are generally quite good.



Map showing the distribution of 5C type areas in the WMMC

Total no. of 5C type TAEs =4 Proportion of WMMC area = 0.8%

Small shopping centre at Penn, outer Wolverhampton.

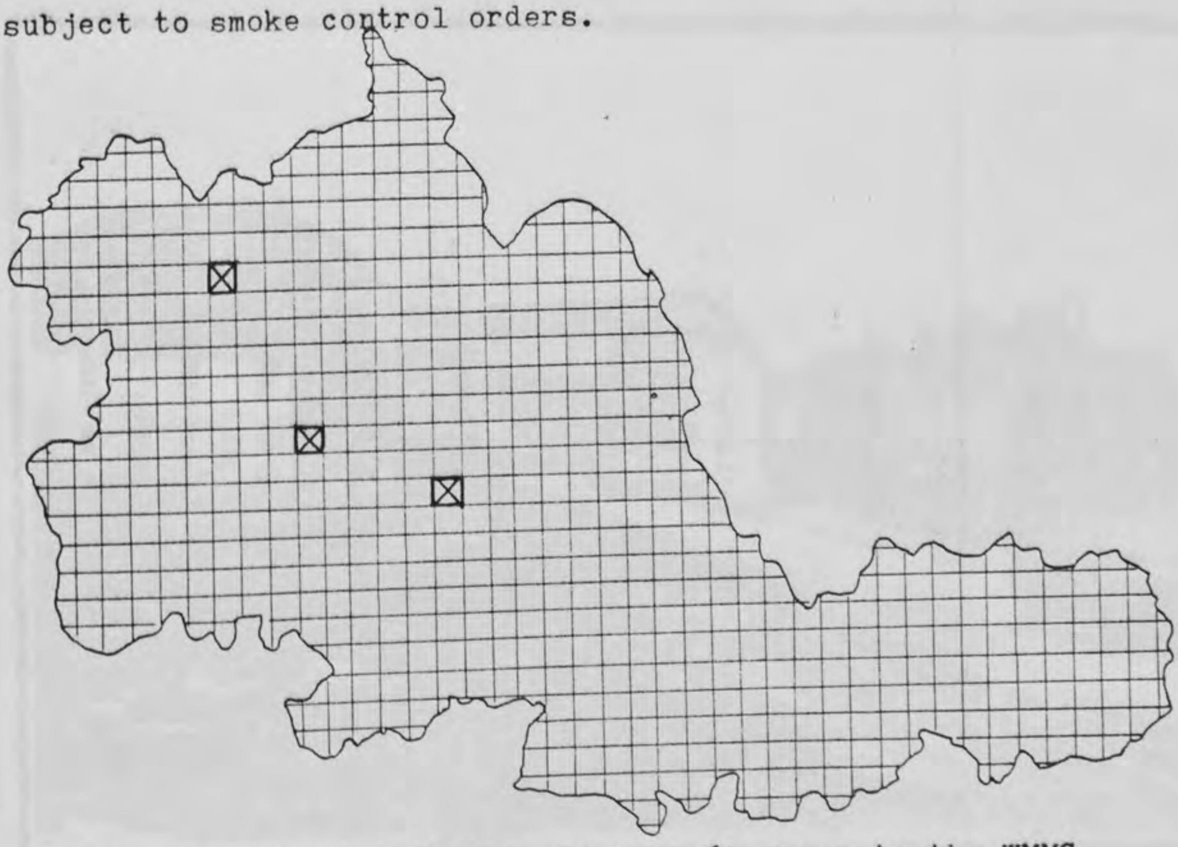
On the Western fringes of the Black Country; Amblecote, a former mining village.

TAE TYPE 6A: INDUSTRIAL/COMMERCIAL MIX, DENSE ROAD NETWORK

Environmental predictions

DATA TYPE	AMBIENT NOISE L_{10}, L_{90}, L_{eq} (dBA)	SULPHUR DIOXIDE ($\mu g\ m^{-3}$)	AREA APPEARANCE (Score)	AGGREGATE CONDITIONS (Rank)
Mean conds	69.7 59.5 66.2	134	2	-
Rank	2	1	2=	1
TAE group	1 - -	1	1	1

General description Old industrial centres in the Black Country. Commercial activities are commonly surrounded by land under predominant industrial use, but also with a significant amount of residential land interspersed amongst the industry. Exposure levels are therefore high, and the overall environmental conditions are lower than for any other TAE type. Air pollution is often especially severe because of the combination of all three types of emission, together with the fact that such areas are rarely subject to smoke control orders.



Map showing the distribution of type 6A areas in the WMMC

Total no. of type 6A TAEs = 3 Proportion of WMMC area = 0.6%

Heavily-trafficked shopping street adjoining an industrial area West of Wolverhampton, showing severe street-level smoke and steam.

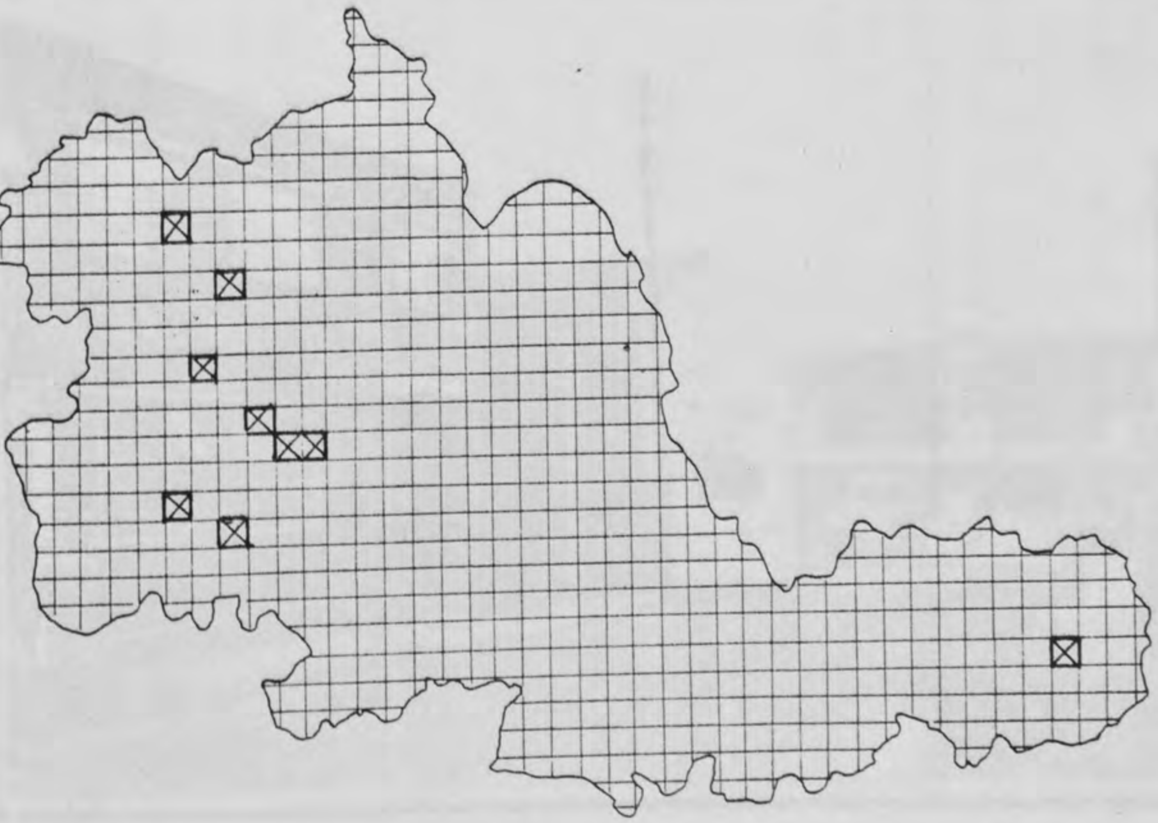
Smethwick; a commercial street, including cinema, bordering a derelict and demolished industrial site.

TAE TYPE 6B: INDUSTRIAL/COMMERCIAL MIX, MEDIUM NETWORK DENSITY

Environmental predictions

DATA TYPE	AMBIENT NOISE L_{10}, L_{90}, L_{eq}	SULPHUR DIOXIDE ($\mu g\ m^{-3}$)	AREA APPEARANCE (Score)	AGGREGATE CONDITIONS (Rank)
Mean conds	66.8 60.1 64.9	109	2	-
Rank	3	6	1	2
TAE group	2	2	1	1

General description Typical of the small industrial town centres that are scattered throughout the Black Country. As with type 6A, the commercial and industrial land uses are accompanied by substantial residential areas , and smoke control zones are infrequent. Environmental conditions are very poor and exposure is high.



Map showing the distribution of 6B type areas in the WMMC

Total no. of type 6B TAEs = 9 Proportion of WMMC area = 1.6%

Willenhall town centre, surrounded by Black Country industry as evidenced by the nearby stack.

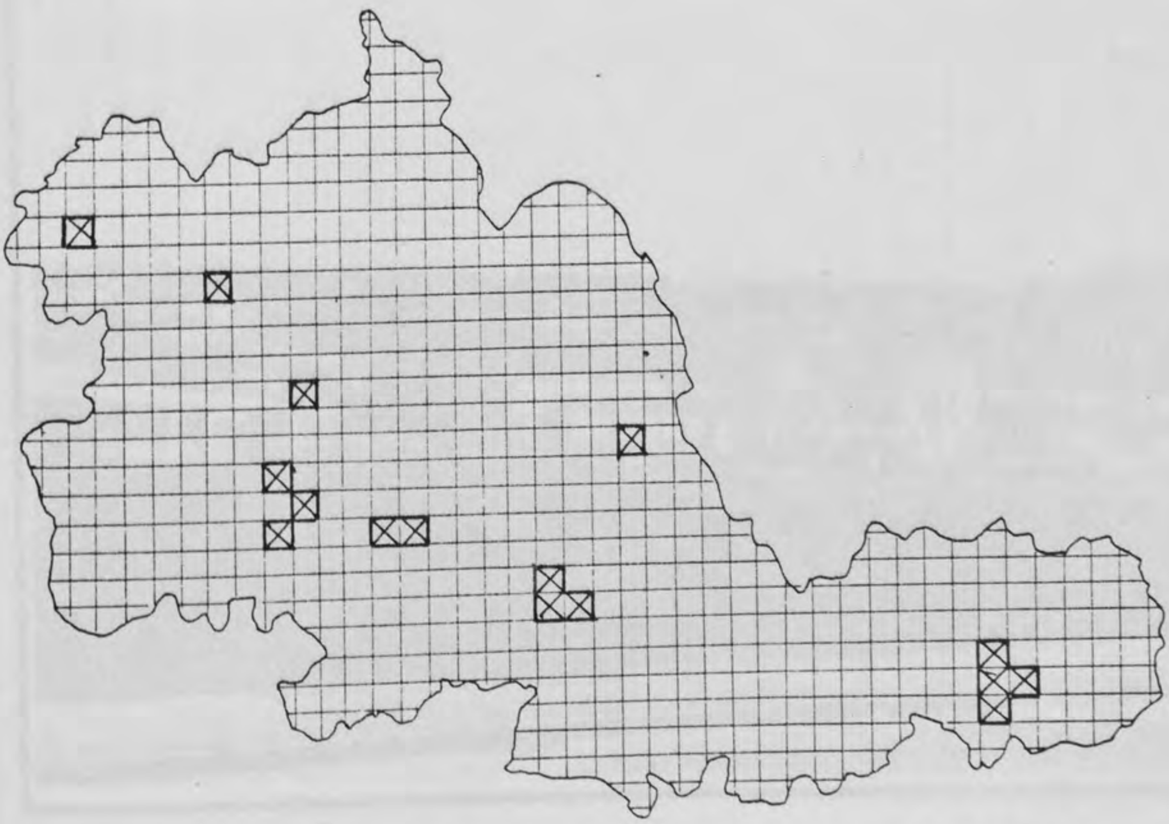
A forging plant less than 100m from a junction with the main shopping street in Cradley Heath (Black Country).

TAE TYPE 7A: RESIDENTIAL/OPEN SPACE, DENSE ROAD NETWORK

Environmental predictions

DATA TYPE	AMBIENT NOISE L_{10}, L_{90}, L_{eq} (dBA)	SULPHUR DIOXIDE ($\mu g\ m^{-3}$)	AREA APPEARANCE (Score)	AGGREGATE CONDITIONS (Rank)
Mean conds	59.4 49.6 56.1	78	8	-
Rank	11 - -	15	17	15
TAE group	3	4	5	4

General description The more modern residential areas near to city centres, where public open space has been purposely created. Residential buildings consist of Council flats or tower blocks, or modern owner-occupied estates. Environmental conditions are generally quite good.



Map showing the distribution of type 7A areas in the WMMC

Total no. of type 7A TAEs = 16 Proportion of WMMC area = 2.8%

Council flats and surrounding recreational areas in Wolverhampton.

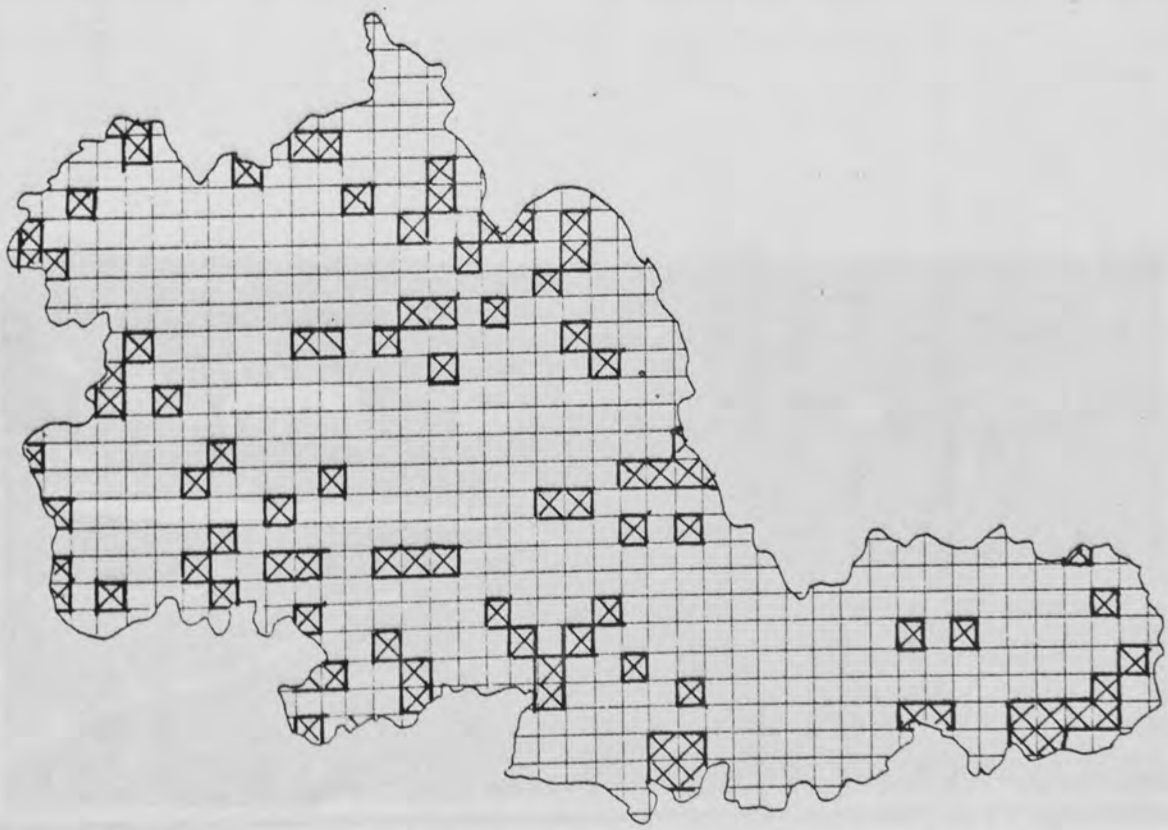
A grassed area set in a modern, high density owner-occupied estate in Whoberley, Coventry.

TAE TYPE 7B: RESIDENTIAL/OPEN SPACE MIX, MEDIUM DENSITY NETWORK

Environmental predictions

DATA TYPE	AMBIENT NOISE L_{10}, L_{90}, L_{eq} (dBA)	SULPHUR DIOXIDE ($\mu g\ m^{-3}$)	AREA APPEARANCE (Score)	AGGREGATE CONDITIONS (Rank)
Mean conds	54.7 47.2 51.8	82	7	-
Rank	16	12	16	16
TAE group	4 - -	4	4	4

General description A common area type in the County, generally located towards the outer parts of the conurbation, as shown by the map. Typical examples are the suburban housing areas in the vicinity og public parks or allotments. Environmental conditions are generally good and the socio-economic status of residents is average or somewhat above.



Map showing the distribution of type 7B areas in the WMMC

Total no of type 7B TAEs = 115 Proportion of WMMC area = 20.2%

Recreational parkland in a suburban residential area near Penn, Wolverhampton.

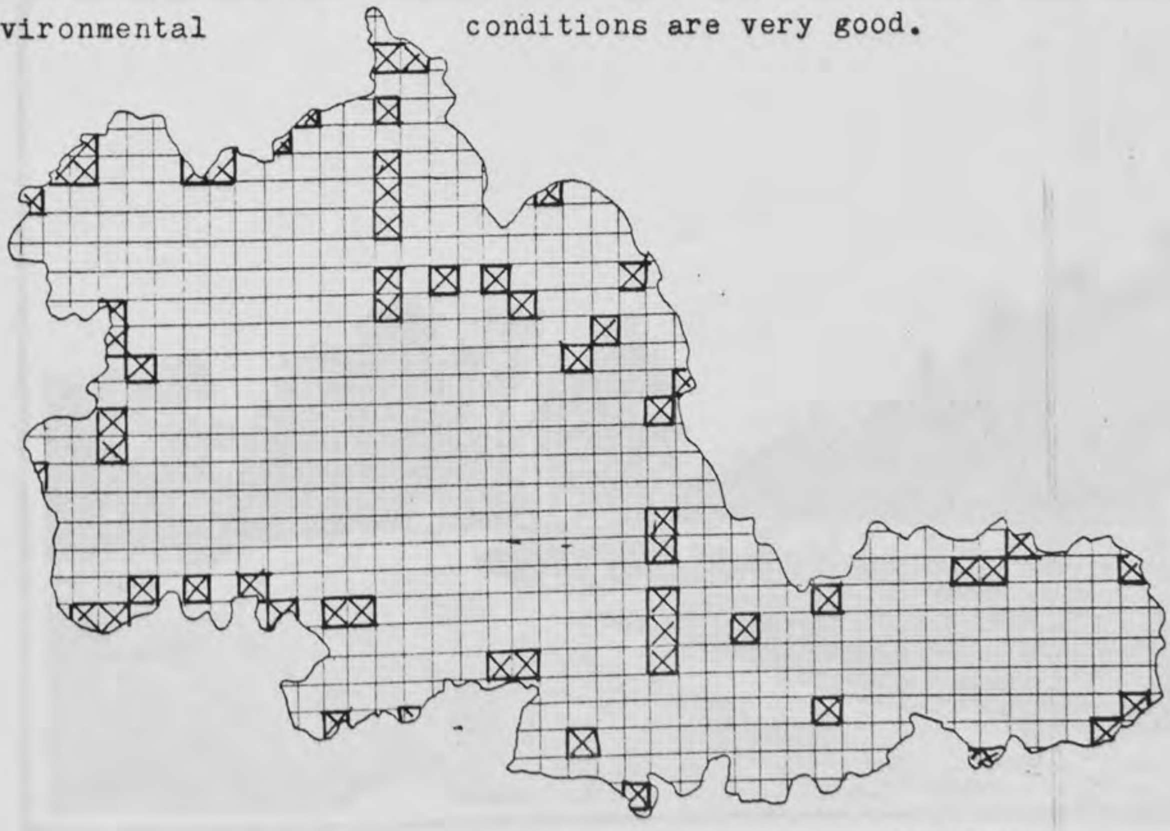
Private allotments bordering a residential area in the Western suburbs of Coventry.

TAE TYPE 7C: RESIDENTIAL/OPEN SPACE, SPARSE ROAD NETWORK

Environmental predictions

DATA TYPE	AMBIENT NOISE L_{10}, L_{90}, L_{eq} (dBA)	SULPHUR DIOXIDE ($\mu g\ m^{-3}$)	AREA APPEARANCE (Score)	AGGREGATE CONDITIONS (Rank)
Mean conds	51.6 44.4 48.8	63	8	-
Rank	18	18	14=	17
TAE group	5	5	4	5

General description A common area type on the urban fringes, usually characterised by spacious semi-detached or detached owner-occupied housing at low densities, with large gardens and surrounded by public open space (e.g. golf courses) or countryside; alternatively the areas may be small rural settlements such as those found in Solihull. The map shows the prevalence of a band of 7C type areas around the whole perimeter of the conurbation. The socio-economic status of residents is predominantly high, and environmental conditions are very good.



Map showing the distribution of 7C type areas in the WMMC

Total no. of type 7C areas = 50 Proportion of WMMC area = 8.8%

Large owner-occupied house backing onto open countryside in Solihull.

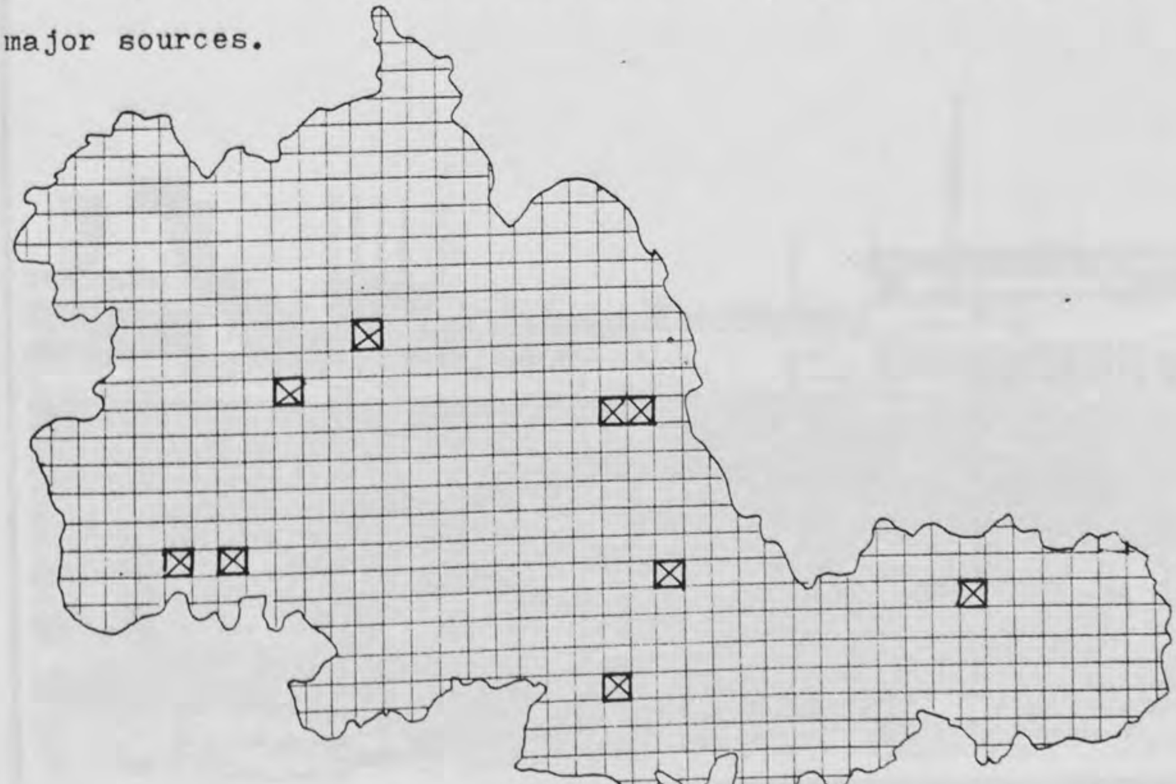
Small rural settlement: houses beside a village lane in Solihull District.

TAE TYPE 8B: INDUSTRIAL/OPEN SPACE MIX, MEDIUM DENSITY NETWORK

Environmental predictions

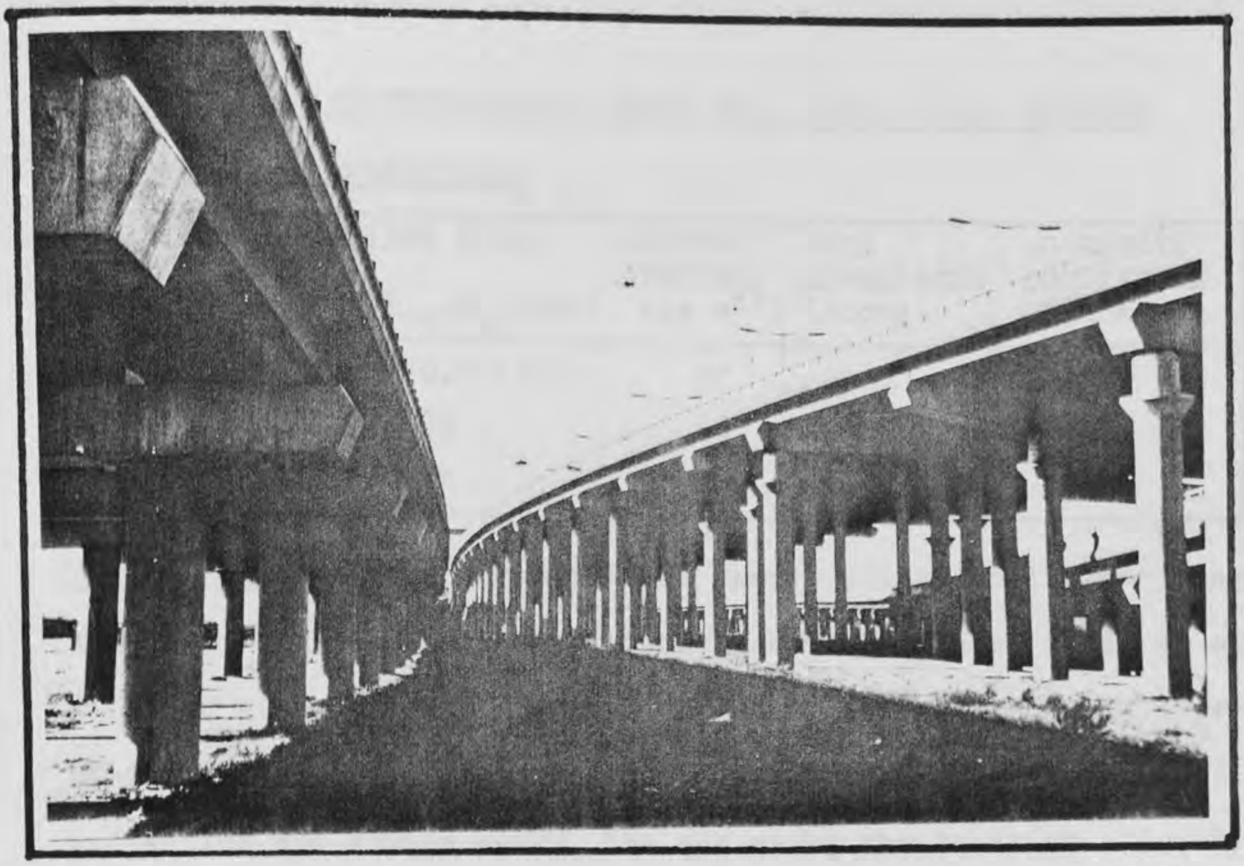
DATA TYPE	AMBIENT NOISE $L_{10}, L_{90} L_{eq}$ (dBA)	SULPHUR DIOXIDE ($\mu g\ m^{-3}$)	AREA APPEARANCE (Score)	AGGREGATE CONDITIONS (Rank)
Mean conds	64.7 61.8 63.3	79	3	-
Rank	5	14	4	8
TAE group	2	4	2	2

General description Industrial land commonly accompanied by large amounts of derelict or vacant land. Such areas are found where former industrial land is now disused (as often in the Black Country) or where the industry needs the open space for dumping or storage. Such areas, frequently found in association with transport routes(e.g. railways, motorways, canals) are usually at some distance from the nearest residential areas and so exposure is low. Noise and area appearance conditions are poor but air pollution tends to be low due to the prevalence of open space and the lack of major sources.

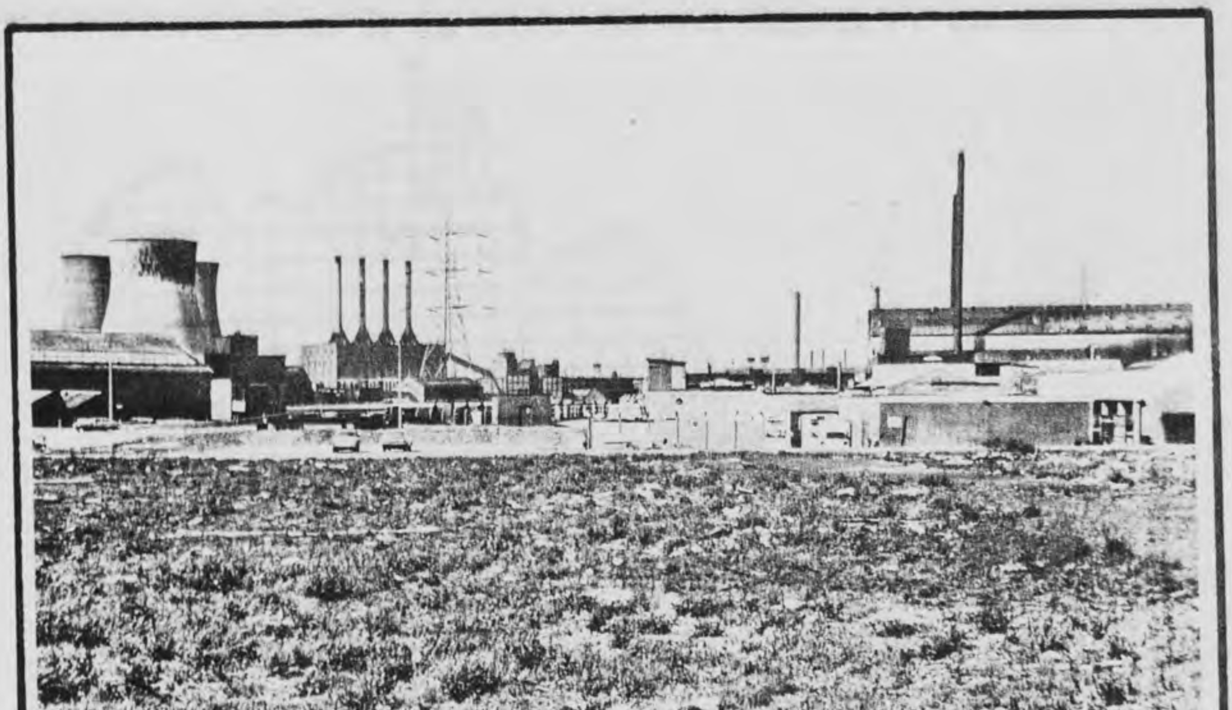


Map showing the distribution of 8B type areas in the WMMC

Total no. of 8B type TAEs = 9 Proportion of WMMC area = 1.6%



The elevated M5/M6 intersection near Yew Tree, West Bromwich. The intersection stands on a large area of open derelict land formerly used in mineral extraction.



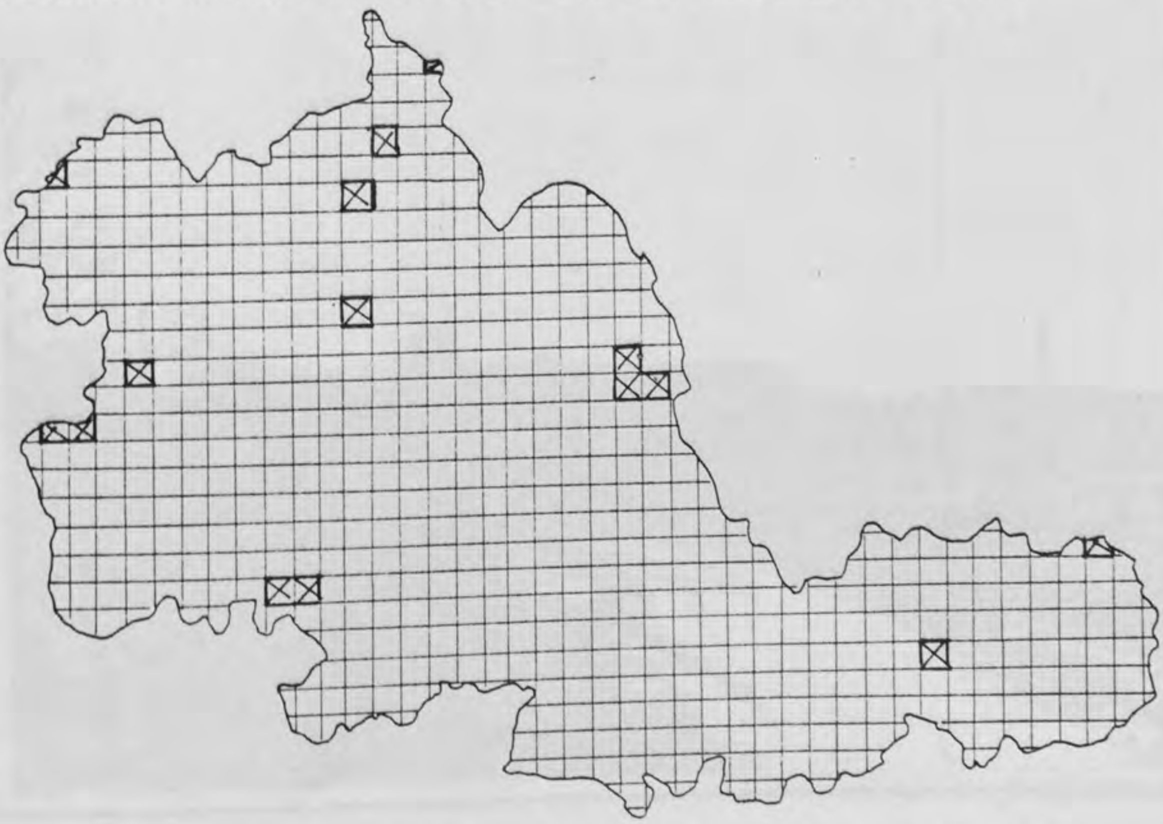
Derelict land in the large industrial area around the Okker Hill power station, near Wednesbury (Black Country).

TAE TYPE 8C: INDUSTRIAL/OPEN SPACE MIX, SPARSE ROAD NETWORK

Environmental predictions

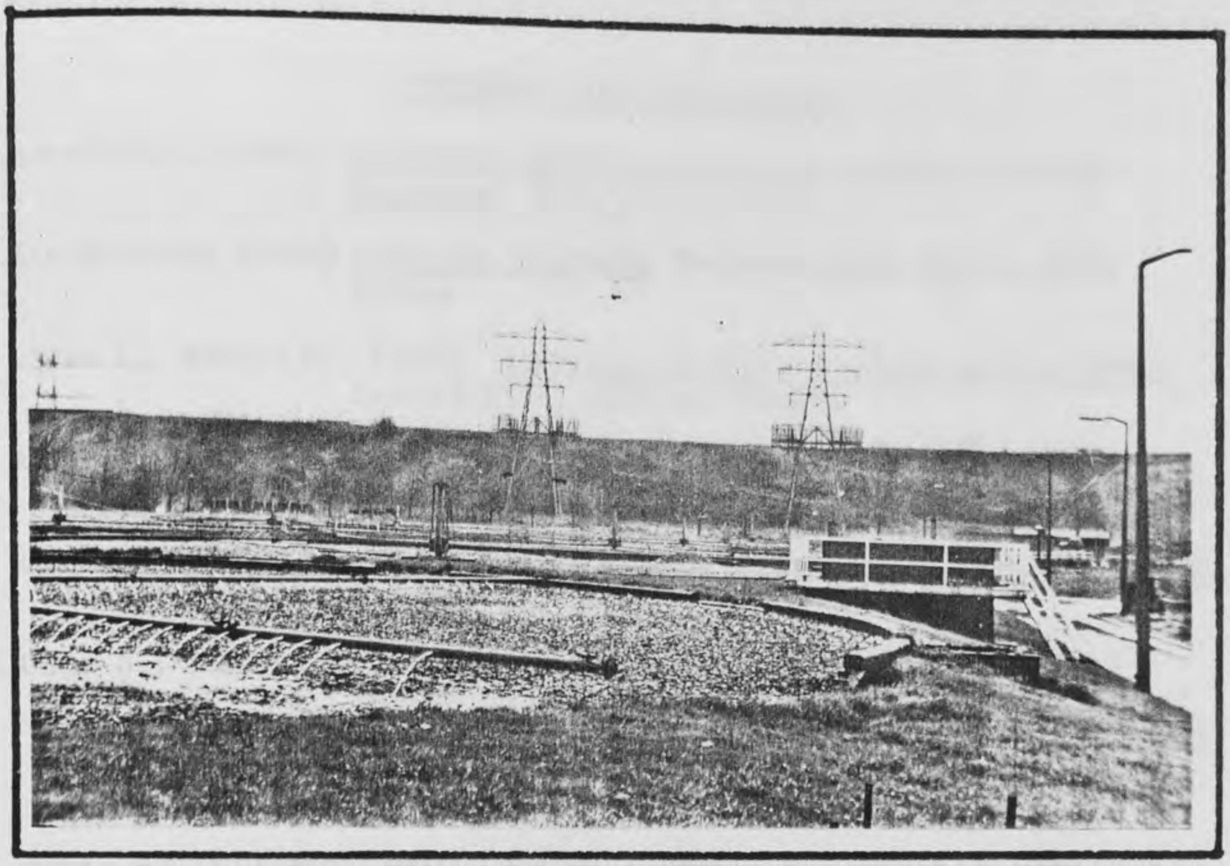
DATA TYPE	AMBIENT NOISE L_{10}, L_{90}, L_{eq} (dBA)			SULPHUR DIOXIDE ($\mu g\ m^{-3}$)	AREA APPEARANCE (Score)	AGGREGATE CONDITIONS (Rank)
Mean conds	56.5	50.3	53.9	77	3	-
Rank	15			16	5	12
TAE group	4	-	-	4	2	4

General description Areas of open space, often derelict or disused land but also including productive agricultural land, in association with low-density industrial activity often of the type needing large areas of open space for dumping - such as mineral extraction and sewage works. The map shows the location of such areas on the fringes of the conurbation. As with type 8B exposure is low. Ambient noise and air pollution levels are low due to the lack of sources; area appearance is poor however because of the extensive amount of derelict land and dumping of wastes.



Map showing the distribution of type 8C areas in the WMMC

Total no. of type 8C TAEs = 17 Proportion of WMMC area = 3.0 %



Sewage works, power lines and a canal beside the M6 to the southwest of Walsall.

Oak Lane, Kingswinford: a large mineral extraction site in current use on the Western edge of the County.

REFERENCES AND BIBLIOGRAPHY

Ackoff R.L. (1962) Scientific method: optimising applied research decisions Wiley, New York

Air Ministry (1962) Observers Handbook Meteorological Offic, HMSO, London

Alden J., Morgan R., (1974) Regional planning: a comprehensive review Leonard Hill, Leighton Buzzard

Alderton D.L. (1962) "Symposium on the dispersion of chimney gases" Int. J. Air and Water Pollution 6, 85-100

Alonso W. (1968) "Predicting best with imperfect data" JAIP, July 1968, 248-255

Ammer U., Bechet G., Bents D., Rosenpranz D., Rosenpranz A., (1976) Ecological mapping of the community: Elaboration of Scheme for the classification of community territory on the basis of its environmental characteristics Report and Recommendations, Brussels

Anderson P.M. (1970) "Trend Surface analysis in studies of urban air pollution" Atmospheric Environment 4 (2) 129-147

Attenborough K., Clark S., Utley W.A. (1976) "Background noise levels in the United Kingdom" Journal of Sound and Vibration 48(3) 359-375

Averous C. (1978) Personal communication OECD, Paris

Ball D.J. (1976) "An air pollution emissions inventory for the Greater London area" Clean Air, Spring 1976, S, 21

_________ (1978a) Personal Communication Greater London Council Scientific Services Dept., London

_________, Bernard R.E. (1978) "The Greater London air pollution emissions inventory" Atmospheric Environment 12, 975-978

_________, Hume R. (1977) "The relative importance of vehicular and domestic emissions of dark smoke in Greater London in the mid-1970's" Atmospheric Environment 11, 1065-1073

Balchin P.N., Kieve J.L. (1977) Urban Land Economics, McMillan, London

Barratt R.S. (1976) "Atmospheric pollution - some problems in measuring particulate matter" Public Works Congress 1976, Environmental Health Officers Association.

_________ (1978) Personal Communication Birmingham District Council Environmental Protection Unit, Birmingham.

Batty M. (1978) "Speculations on an information-theoretic approach to spatial representation" In Spatial Representation and Spatial Interaction, Masser I., Brown D. (eds), Martinus Nijhoff Social Sciences Division, Netherlands

________, Sammons R. (1978) "On searching for the most informative spatial pattern" Environmental and Planning A, 10, 747 - 779.

Benarie M.M. (1976) Urban Air Pollution Modelling Without Computers US Environmental Protection Agency EPA - 600/4-76-055, N. Carolina

Benedetto G., Spagnolo R. (1977) "Traffic noise survey of Turin, Italy" Applied Acoustics 10(3), 201-222

Berry B.J.L. (1974) Land Use, Urban Form and Environmental Quality US Environmental Protection Agency, Research Paper T55, Illinois

Bigham D.A. (1973) The Law and Administration relating to Protection of the Environment Oyez, London

Blalock H.M. (1960) Social Statistics McGraw Hill, New York

________ (1973) An Introduction to Social Research Prentice Hall, New Jersey

Broadbent T.A. (1970) "Notes on the design of operational models" Environment and Planning, 2, 469-476

Boulind H.F. (1952) Sound: An Advanced Course, John Murray, London

British Standards Institution (1967, revised 1975) "Method of rating industrial noise" BS 4142 British Standards Institution

Buchanan C. (1971) The Prospect for Housing Nationwide Building Society Report, London

________ (1973) "Environmental quality of the housing stock", in A.M. Voorhees and Associates, Tyne-Wear Plan - Urban Strategy, London

Buchanan J. (1971) "Evaluation of the housing stock and its environment" JRTPI 57(8), 372-375

Burgess E.W. (1929) "Urban Areas" In Chicago: An Experiment in Social Science Research, Smith T.U., White L.D. (eds), University of Chicago Press, Chicago

Busse A.D., Zimmerman J.R. (1973) Users guide for the Climatological Dispersion Model US Environmental Protection Agency EPA - R4 - 73 - 024 Report

Calder K.L. (1973) A climatological model for multiple source urban air pollution US Environmental Protection Agency EPA-R4-73-024 Report

Cane S. (1977) Environmental Quality in Residential Areas: A Social Survey Approach to Improvement Problems, Unpublished PhD Thesis, JURUE, University of Aston

Catanese A.J. (1972) Scientific Methods of Urban Analysis Intertext, Illinois University

Catlow J., Thirlwall C.G. (1976) "Environmental impact analysis study: interim report" DoE Research Report 11, HMSO, London

CEL (1979) Conference on Ambient Noise Measurement Computer Electronics Limited, West Bromwich

Chandler T.J. (1965) The Climate of London Hutchinson, London

Cheshire County Council (1977) Structure Plan Report of Survey Revised Edition, County Hall, Chester

Chorley R.J., Haggett P. (1965) "Trend surface mapping in geographical research" Trans. Inst. British Geographers 37, 47-67

Civic Trust for the North West (1971) Environmental Quality - A Measurement System, Liverpool District Council, Liverpool

Clamp P. (1976) "Evaluating English Landscapes - some recent developments" Environment and Planning A,8,79-92

Clark B. (1976) "Evaluating environmental impacts", in Environmental Impact Assessment, O'Riordon T., Hey R. (eds) Saxon House, Farnborough

Cliff A.D., Ord J.K. (1973) Spatial Autocorrelation Monographs in spatial and environmental systems analysis, Pion, London

Cows P. (1959) "Definition and measurement in Physics" cited in Ackoff R.L. Scientific Method: Optimising Applied Research Decisions, Wiley, New York

Council on Environmental Quality (1974) Fifth Annual Report US Government Printing Office, New York

Craik C.H. (1968) "Comprehension of the Everyday Environment" JAIP 34, 29-33

Csanady G.T. (1973) "Effect of plume rise on ground level pollution" Atmospheric Environment 7(1), 1-16

Cullingworth J.B. (1974) Town and Country Planning in England and Wales Allen and Unwin, London

Cunniff P.F. (1977) Environmental Noise Pollution Wiley, New York

Dalkey N. (1969) "An experimental study of group opinion: the Delphi method" Futures 1(5) 408-426

Davies B.E., Roberts L.J. (1976) -"The role of the computer in trace element surveys with special reference to package programs" Welsh Soils Discussion Group, Report No.17 University College of Wales, Aberystwyth

Davis R.M., Stacey G.S, Nehman G.J., Goodman F.K. (1975) "An approach to trading off economic and environmental values in industrial land use planning" Geographical Analysis 7 (4) 397-410

Delaney M.E. (1971) "Propagation of traffic noise in typical suburban situations" National Physical Laboratory Report Ac54, Dept. of Trade and Industry

_________ (1977) "Sound propagation in the atmosphere: a historical review" Acustica 38(4) 201-223

Demuynck M., Dams R. (1975) "One year study of total suspended particulate matter at 14 locations in Belgium" Atmospheric Environment 9, 1033-1035

Department of the Environment (1972) Sample Housing Condition Survey DoE Welsh Office, Area Improvement Note 2, HMSO, London

_________ (1974) The Monitoring of the Environment in the United Kingdom HMSO, London

_________ (1976a) "The value of standards for the external residential environment" Research Report 6 HMSO, London

_________ (1976b) "Development Plan Evaluation and Robustness" Research Report 5 HMSO, London

_________ (1976c) Mapped concentrations of smoke and sulphur dioxide over the UK HMSO, London

Dickert T.G., Domeny K.R. (eds) (1974) Environmental Impact Assessment: Guidelines and Commentry University Extension, University of California, Berkeley, California

Dickinson G.C. (1973) Statistical Mapping and the Presentation of Statistics Edward Arnold, London

Dickinson P.T., Large J.B. (1975) "The problem of modelling community noise" Journal of sound and vibration 43(2), 419-427

Drake A.W. (1972) (ed) Analysis of Public Systems MIT Press

van Driel I.N. (1977) "Computer mapping for guiding suburban development" Ekistics 44 (264), Nov, 266-273

Dror Y. (1968) Public Policymaking Reexamined Chandler

Edel M., Rothenberg J. (1972) (eds) Readings in Urban Economics, McMillan, London

Eden C. (1976) Decision models, systems design and dynamic goal systems Journal of Systems Engineering 4(2) 23-47

Edwards A.L. (1964) Statistical methods for the behavioural sciences, Holt, Rinehart, and Winston, New York

Eldred K.M. (1975) "Assessment of community noise" Journal of Sound and and Vibration 43(2), 137-146

Elsom D.M., Chandler T.J. (1978) "Meteorological controls upon ground level concentrations of smoke and sulphur dioxide in two urban areas of the UK" Atmospheric Environment 12, 1543-1554

Environmental Protection Agency (1971) "Effects of Noise on People", Report No. NT 1D 300 7, US Govt. Printing Office, Washington

Faludi A. (ed) (1973) A Reader in Planning Theory Pergamon, Oxford

Fines K.D. (1968) "Landscape evaluation - a research project in East Sussex" Regional Studies 2, 41-35

Fisk D.J. (1973) "Statistical sampling in community noise measurement" Journal of Sound and Vibration 30 (2) 221-236

Freeman A.M. (1972) "Dist b tion of environmental quality" in the Economics of Environmental Policy, Freeman A.M., Haverman R.H., Kneese A.V. (eds), New York

Frenkiel F.N. (1956) "Atmospheric Pollution and Zoning in an urban area" Scientific Monthly 82, 194-203

Garlauskas A.B. (1975) "Conceptual Framework of environmental management" Journal of Environmental Management 3, 185-203

Garnett A. (1967) "Some climatological problems in urban geography with reference to air pollution" Trans. Institute of British Geographers 42, 21-43

_________ (1971) "Sheffield emerges from the smoke and grime" Geographical Magazine Nov. 1970, 122-128

_________ (1973) "Emissions, air pollution and the atmospheric environment" J. Institute of Fuel 46, 39-45

Gifford F.A., Hanna S.R. (1973) "Modelling Urban Air Pollution" Atmospheric Environment 7, 131-136

Gilford C.L.S., Norris C.A. (1973) The 1972 West Midlands Noise Survey Unpublished paper, Dept. of Construction and Environmental Health, University of Aston in Birmingham

Goldstein I.F., Landowitz L. (1977) "Analysis of air pollution patterns in New York City - can one station represent the large metropolitan area?" Atmospheric Environment 11, 47-52

Goodey B. (1971) Perception of the Environment, CURS Occasional Paper, University of Birmingham

Gordon S.I. (1978) "Performing land-capability evaluation by use of numerical taxonomy" Environment and Planning A, 10, 915-921

Grashof M. (1976) "The assessment of noise from industrial plants by direct assessment and by calculation" Applied Acoustics 9 (3) 177-192

Greig-Smith P. (1957, second edition 1964) Quantitative Plant Ecology Butterworth's Scientific Publications, London

Gulley W.H., Newton C.H. (1972) "Methods of measuring the distribution of socio-economic conditions" Socio-Economic Planning Science 6, 187-195

Hall A.D. (1962) Methodology for Systems Engineering, van Nostrand, Princetown

Harris B. (1965) "New tools for planning" JAIP Special Issue 31(2) 90-95

__________ (1967a) Quantitative Models of Urban Development University of Pennsylvania

__________ (1967b) "The city of the future - the problem of optimal design" Papers of the Regional Science Association, 19

Howard R.A. (1968) "The foundation of decision analysis" IEEE Transactions on Systems and Cybernetics 4(3), Sept., 211-221

Huang D.S. (1970) Regression and econometric methods Wiley, New York

Inhaber H. (1974) "Environmental quality: outline for a national index for Canada" Science 186, 798-805

__________ (1976) Environmental Indices, Wiley, New York

Johnson W.B., Ludwig F.L., Dabberdt W.F., Allen R.J. (1973) "An urban diffusion simulation model for carbon monoxide" J. Air Pollution Control Association 23(6), 490-498

JURUE (1975) West London Study: The Environmental Consequences in Hammersmith of Alternative Road Proposals Joint Unit for Research on the Urban Environment, University of Aston

__________ (1976) Conceptual Frameworks for Environmental Evaluation and Research Report for the Dept. of the Environment, Joint Unit for Research on the Urban Environment, University of Aston

__________ (1977a) Urban Fabric: Building Intensity Report for the Building Research Establishment, Joint Unit for Research on the Urban Environment, University of Aston

__________ (1977b) The Environmental Impact of Transport in the West Midlands Metropolitan County: Vol.1 - A Survey Report for the West Midlands County Council, Joint Unit for Research on the Urban Environment, University of Aston

Kain J.F., Quigley J.M. (1970) "Evaluating the quality of the residential environment" Environment and Planning A,2, 23-32

Karpe H.J., Scholz D. (1976) "Environmental pollution and its social impact" NATO Conference Paper Oct. 1976, Istanbul

Keddie A.W.C., Roberts G.H., Williams F.P. (1976) "Application of numerical modelling to air pollution in the Forth Valley"; in Brebbia C.A. (ed), Mathematical Models for Environmental Problems, (Proceedings of International Conference, Southampton University Sept. 1975) Pentach Press, London

Keeney R.L. (1972) "Utility Functions for multi-attributed Consequences" Management Science 18a (5) 276-286

Kendall M.G. (1948) Rank Correlation Methods Griffin, London (cited in Siegel 1956)

Kendig H. (1976) "Cluster analysis to classify residential areas: a Los Angeles application" JAIP 42(3), 286-294

Kershaw K.A. (1964) Quantitative and dynamic ecology Edward Arnold, London

Kneese A.V., Bower B.T. (1972) Environmental Quality Analysis RFF, New York

Kruskal J.B. (1964) "Multidimensional scaling by optimising goodness of fit to a non-metric hypothesis" Psychometrika 29, 1-27

LaBreche R.M., Mendias M.L., Putnicki G.J. (1976) "Inexpensive Community noise assessments for medium and small cities" Sound and Vibration 10 (12), 12-14

Lamb R.G., Neiburger M. (1971) "An interim version of a generalised urban air pollution model" Atmospheric Environment 5, 239-264

Lee C. (1973) Models in Planning Pergamon, Oxford

Lee N., Wood C.M. (1972) "Planning and pollution" JRTPI 37, 137-142

Lettau H.H. 1970 "Physical and meteorological basis for mathematical models of urban diffusion processes" Proc-symp-on Multiple Source Urban Diffusion Models EPA AP-26

Lichfield N., Kettle P., Whitbread M. (1975) Evaluation in the Planning Process Pergamon, London

Lowry I. (1965) "A short course in model design" JAIP Special Issue 31(2) 138-146

Lucas D.H. (1958) "The atmospheric pollution of cities" Int. J. Air Pollution 1, 71-86

Marsh K.J., Foster M.D. (1967) "An experimental study of the dispersion of the emissions from chimneys in Reading" Atmospheric Environment 1, 527-550

Martin A., Barber F.R. (1967) "Investigations of sulphur dioxide pollution around a modern power station" Journal of the Institute of Fuel 39, 294-307

Masser I. (1972) Analytical Models for Urban and Regional Planning David and Charles, Newton Abbot

_________ and Brown P. (1978) (eds) Spatial Representation and Spatial Interaction Martinus Nijhoff Social Sciences Division, Netherlands

Meetham A.R. (1945) "Atmospheric Pollution in Leicester" Atmospheric Pollution Research Technical Paper No.1, Dept. of Scientific and Industrial Research, HMSO, London

Merseyside County Council (1976) County Structure Plan Report of Survey, County Council, Liverpool

Mills E.S. (1970) "Urban density functions" Urban Studies 7(1), 207-220

_________ (1972) Urban Economics Scott, Foresman, London

McLoughlin B. (1969) Urban and Regional Planning: A Systems Approach Faber and Faber, London

McLoughlin J. (1972) The Law Relating to Pollution Manchester University Press, Manchester

Mochizuki T. (1969) "City noises in Tokyo" Journal of the Acoustical Society of Japan, 146-167

Myrup L.O., Rogers D.L. (1976) "The relationship between land use and emission of automotive air pollution" Int. Journal of Environmental Studies 8, 269-275

Noise Advisory Council (1978) "A guide to the measurement and prediction of the equivalent continuous sound level L_{eq}" Report of the Technical Sub-Committee Noise Advisory Council, HMSO, London

Noll K.E., Miller T.L., Claggett M. (1978) "A comparison of three highway line dispersion models" Atmospheric Environment 12 1323-1329

Noll K.E., Miller T.L., Norco J.E., Raufer R.K. (1977) "An objective air monitoring site selection methodology for large point scores" Atmospheric Environment 11, 1051-1059

OECD (1976) "Urban environmental indicators: a tool to assess the quality of man's urban environment" Special Meeting on Urban Environmental Indicators, Sept. 21-23, OECD, Paris

Pasquill F. (1961) "The estimation of the dispersion of air borne material" Meteorological Magazine 90, 33-50

_________ (1971) "Atmospheric dispersion of pollutants" Quarterly Journal of the Royal Meteorological Society 97, 369-395

Pechan E.H. (1975) "Relating environmental modelling to policy issues and decisions" Ecological Modelling 1 (1) 27-38

Pelletier J. (1967) "Enquetes de pollution atmospherique dans l'environment" Poll Atm 36, 240-252

Perloff H.S. (1969) "Framework for dealing with the urban environment", in Perloff H.S. (ed), Quality of the Urban Environment, Wiley, New York

_________ (1972) "Environmental Indicators - an overview" in Environmental Design - Research and Practice EURA Conference, Los Angeles, University of California, 1972.

Peterson J.T. (1970) "Distribution of sulphur dioxide over metropolitan St. Louis as described by empirical eigenvectors" Atmospheric Environment 4, 501-518

Pocock R.L. (1976) "Theory, aims and methodology for research in the measurement and prediction of ambient environmental quality in urban areas" Research Working Note RP3, JURUE, University of Aston

_________ (1977a) "Progress on the development of a methodology for the measurement and prediction of ambient environmental conditions in urban areas" Paper to Seminar 10th Feb 1977, JURUE, University of Aston

_________ (1977b) "Preliminary Report on the JURUE Ambient Noise Survey" Paper to Colloquium 6th Dec 1977, JURUE, University of Aston

Pooler F. (1961) "A prediction model of mean urban pollution for use with standard wind roses" Atmospheric Environment 4(314), 199-211

Prabhu B.J.S., Chakraborty R.L.M. (1978) "An urban noise model for planners" Journal of Sound and Vibration 58(4) 595-597)

Prahm L.P., Christensen M. (1977) "Validation of a multiple-source Gaussian air quality model" Atmospheric Environment 11, 791-795

Pratt J.W. (1974) Statistical and mathematical aspects of pollution problems Harvard Business School, Mass.

Price A.J. (1972) "Community noise survey of Greater Vancouver" J. Acoustical Society of America 52, 488-492

Ragland K.W. (1973) "Multiple box model for dispersion of air pollutants from area sources" Atmospheric Environment 7, 1017-1032

Raiffa H. (1968) Decision Analysis: Introductory Lectures on Choices under Uncertainty Addison - Wesley, Mass.

Randerson D. (1970) "A numerical experiment in simulating the transport of sulphur oxides through the atmosphere" Atmospheric Environment 4, 615-632

Reynolds O. (1895) "On the dynamic theory of incompressible viscous fluids and the determination of the criterion" Phil. Tr. Royal Society of London 186(17), 123-164

Reiquam H. (1970) "An atmospheric transport and accumulation model for airsheds" Atmospheric Environment 4, 233-247

Roberts O.T.F. (1923) "The theoretical scattering of smoke in a turbulent atmosphere" Proc. Royal Society 104 (A 728), 640-654

Robinson A.H. (1956) "Analysis of areal data" Annals Assoc. Am. Geographers 46, 233-238

Robson A.J. (1977) "The effect of urban structure on the concentration of pollution" Urban Studies 14, 89-93

Royal Commission on Environmental Pollution (1971) First Report HMSO, London

__________ (1974) "Pollution control: progress and problems" Fourth Report, HMSO, London

Russell V.S. (1974) "Pollution: Concept and definition" Biological Conservation 6 (1) 157-170

Safeer H.B. (1973) "Community noise levels: a statistical phenomenon" Journal of Sound and Vibration 26(4) 489-502

__________, Wesler J.E., Rickley E.J. (1972) "Errors due to sampling in community noise levels" Journal of Sound and Vibration 24(3) 365-376

Scholes W.E., Salvidge A.C. (1973) "Statistical analysis from a sound level meter" Applied Acoustics 5, 111-117

Schuler R.E. (1973) "Air quality improvement and long-run urban form" Regional Science Association Papers 32 Atalanta Meeting, Nov. 1973, Pennsylvania

Schulz T.J. (1972) "Some sources of error in community noise measurement" Sound and Vibration 6, 18-27)

Scorer R.S. (1968) Air pollution Pergamon Press, London

Seneca J.T., Taussig M.K. (1974) Environmental Economics Prentice Hall, New Jersey

Senko A., Kirshnan P.V. (1971) Urban noise survey methodology Goodfriend L.S. and Associates, Report 4-1262, New York

Sharma V. (1976) "An area-source model for ambient air pollution applications" Atmospheric Environment 10(11) 1027-1032

Siegel S. (1956) Nonparametric Statistics for the behavioural sciences, McGraw-Hill, New York

Singpurwalla N.D. (1974) "Models in Air Pollution" in A Guide of Models In Governmental Planning and Operations, Environmental Protection Agency, Washington

Skibin D. (1975) "Siting of industrial zones near cities" Atmospheric Environment 9, 543-547

Smith F.B., Jeffrey G.A. (1975) "Airborne Transport of sulphur dioxide from the UK" Atmospheric Environment 9 (6/7) 643/660

Solesbury W. (1974) Policy in Urban Planning Pergamon, Oxford

South Yorkshire County Council (1978a) County Environmental Survey, County Council, Barnsley, Yorks

__________ (1978b) Environmental Mapping of the European Community: South Yorkshire Case Study Vols 1 and 2, County Council, Barnsley, Yorkshire.

__________ (1979) Environmental Mapping of the European Community - Final Report County Council, Barnsley, Yorkshire.

Sprent P. (1969) Models in Regression, Methuen, London

Stern, A.C. (1968) Air Pollution Vol. 1 Academic Press, New York

Stevens S.S. (1935) "The operational basis of psychology" American Journal of Psychology 47, 323-330

__________ (1951) "Mathematics, measurement and psychophysics"; In Handbook of Experimental Psychology, Stevens S. (ed) Wiley, New York

Sutton O.G. (1932) "A theory of eddy diffusion in the atmosphere" Proc. Royal Society 135(A), 142-171

__________ (1947) "The theoretical distribution of airborne pollution from factory chimneys" Quarterly J.R. Met. Soc. 73, 426-440

Taylor G.I. (1935) "Statistical theory of turbulence" Parts I-IV, Proc. Royal Society 151(A), 421-478

Theys J. (1976) Environmental assessment of socio-economic systems Paper to NATO Conference, 7th Oct 1978, Istabnul

Tokyo Metropolitan Government (1976) Tokyo Fights Pollution Revised Edition, Research Institute for Environmental Protection, Tokyo Metropolitan Government

Traill M. (1978) "Personal communication" cited in Ecological Mapping of the European Community, South Yorkshire County Council (1978b), Barnsley, Yorkshire

Troy P.N. (1972) "Environmental Quality in four Melborne Suburbs" Australian National University, Melbourne

Tukey J. (1949) "Comparing individual means in the analysis of variance" Biometrics 5, 99-114 (cited in Edwards 1964)

Turner D.B. (1964) "A diffusion model for an urban area" Journal of Applied Meteorology 3(1), 85-91

__________ (1970) Workbook of atmospheric pollution estimates US Environmental Protection Agency AP-26, Washington

__________, Zimmerman J.R., Busse A.D. (1973) "An evaluation of some climatological dispersion models" US Environmental Protection Agency EPA-R4-73-024 Report

Unwin D. (1975) An Introduction to Trend Surface Analysis CATMOG 5 Geological Abstracts, University of East Anglia

University of Manchester (1976) Landscape evaluation: the landscape evaluation research project 1970-75 University of Manchester

Various (1975) "Delphi techniques for forecasting" Technical Forecasting and Social Change 7(2) 113ff

Voorhees A.M. and Associates (1973) Tyne-Wear Plan - Urban Strategy, London

Walters D. (1978) Personal Communication University of Aston in Birmingham

Wathern P. (1976) "The role of impact statements in environmental planning in Britain" Int. Journal of Environmental Studies 9(3) 165-168

Warren Spring Laboratory (1974) National Survey of Air Pollution 1961-1971 Vol.3 - Midlands Department of Trade and Industry, Stevenage

__________ (1975) Smoke and SO_2 contour maps of the UK (Goorich B.D., Keddie A.W.C., Williams F.P., eds) Department of Trade and Industry, Stevenage

Weatherley M.L. (1977) "Estimates of smoke and sulphur dioxide pollution from fuel combustion in the UK, 1975, and 1976" Clean Air, Winter 1977, 4-8

Werczberger E. (1974) "A mixed-integer programming model for the integration of air quality policy into landuse planning" Paper of the Regional Science Association 33, 141-154

West Midlands County Council (1978) County Structure Plan Report of Survey - Environment County Hall, Birmingham

Wigan M.R. (1976) "The estimation of environmental impacts for transport policy assessment" Environment and Planning A, 8(2), 125-145

Williams F.P. (1978) Personal Communication Warren Spring laboratory, Stevenage

Williams H.E., Pocock R.L. (1977) "Environmental quality in the West Midlands", In Joyce F.E. (Ed) Metropolitan Development and Change, Teakfield, Farnborough

Wilson A.G. (1970) "On some problems in urban and regional modelling" CES Working Paper 59, Centre for Environmental Studies, London

Wingo L. (1973) "The quality of life; towards a micro economic definition" Urban Studies 10(1), 3-18

Winstanley J.W. (1952) Textbook on Sound Longmans, London

Wood C.M., Lee N., Luker J.A., Saunders P.J.W. (1974) The Geography of Pollution - a Study of Greater Manchester Manchester University Press, Manchester

Wood C.M. (1976) Town Planning and Pollution Control Manchester University Press, Manchester

World Health Authority (1972) "Air quality criteria and guides for urban air pollutants" WHO Technical Reports Series No.506, Geneva

Wyle Laboratories (1972) Community Noise Report for the U.S. Environmental Protection Agency, U.S. Govt. Printing Office, Washington

Wrigley N. (1977) "Probability Surface mapping - a new approach to trend surface mapping" Trans. Institute of British Geographers New Series 2(2), 129-140

Yerges J.F., Bollinger J. (1973) "Manual traffic noise sampling - can it be done accurately?" Sound and Vibration 7, 23-30

Zetter J.A. (1974) "The application of potential surface analysis to rural planning" JRTPI, February 1974, 544-549