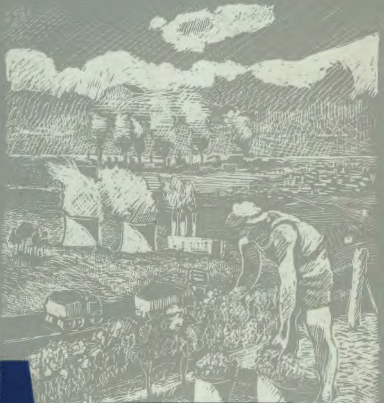
16

CRES Monograph

Air quality and resource development

a risk assessment in the Hunter Region in Australia

A.J. Jakeman and R.W. Simpson

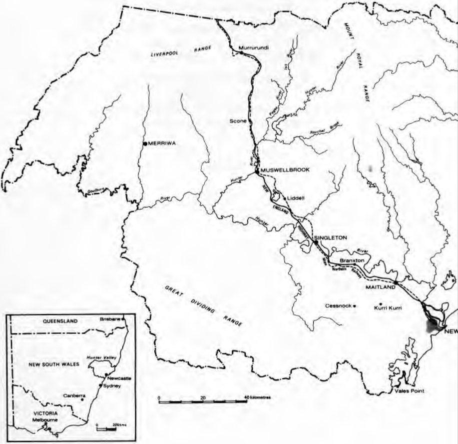


Centre for Res Studies
Australian National University

Air quality and resource development

The Monograph series of the Centre for Resource and Environmental Studies is designed to present the results of CRES research, and the proceedings of conferences and workshops arranged by CRES, which are of public importance. Views expressed in CRES publications are the views of the authors and not those of the Centre or any institution associated with it.

Enquiries should be made to the:
Publications Section,
Centre for Resource and Environmental Studies,
Australian National University,
GPO Box 4,
Canberra ACT 2601
Australia


LIVERPOOL RANGE
Murrurundi
MOUNT ROYAL RANGE
Isis River
Pages River
Hunter River
Rouchel Brook
Scone
MERRIWA
Goulburn River
Hunter River
MUSWELLBROOK
Liddell
NEW ENGLAND HIGHWAY
SINGLETON
River
Branxton
Main Northern Railway
MAITLAND
Cessnock
Kurri Kurri
NEW
GREAT DIVIDING RANGE
Vales Point
0
20
40 kilometres
QUEENSLAND
Brisbane
NEW SOUTH WALES
Hunter Valley
Newcastle
Sydney
Canberra
VICTORIA
Melbourne
0
200 kms

CRES MONOGRAPH 16

Air quality and resource development

a risk assessment in the Hunter Region in Australia

A. J. Jakeman and R. W. Simpson

CENTRE FOR RESOURCE
AND ENVIRONMENTAL STUDIES
AUSTRALIAN NATIONAL UNIVERSITY
1987

National Library of Australia
Cataloguing-in-publication entry

Jakeman, A. J. (Anthony John), 1951–
Air quality and resource development

Bibliography.
Includes index.
ISBN 0 86740 150 8
ISSN 0725-3400

1. Air quality—New South Wales—Hunter River Region. 2. Coal mines and mining—Environmental aspects—New South Wales—Hunter River Region. I. Simpson, R. W. (Rodney William), 1946– . II. Australian National University. Centre for Resource and Environmental Studies. III. Title. (Series: CRES monograph; no.16).

363.7'39263'099442

Designed by Ingrid Slamer/ANU Graphic Design
Typeset in Australia by Union Offset Co. Pty Ltd, Canberra
Printed in Australia by Brown Prior Anderson Pty Ltd, Victoria

Distributed by Publications Section,
Centre for Resource and Environmental Studies,
Australian National University,
GPO Box 4,
Canberra ACT 2601

Foreword

Active development of the black coal resources in the Hunter Region has been a strategy of the New South Wales government for almost a decade. Part of the objective has been to ease high unemployment and arrest the decline of industrial activity within the state and region by mining coal to attract energy-intensive industries. However there has been no comprehensive assessment of the social and environmental effects of continuing resource development within the region.

In mid 1981, with the aid of a NERDDC grant, the Centre for Resource and Environmental Studies responded to this challenge by initiating a study of regional development in the Hunter. Major potential conflicts between coal production and the environment, social values, political priorities and international economic forces were evaluated. The aim was to ensure that public policy issues could be properly canvassed and the various options identified.

Factors which could constrain development include the coal resource base itself, labour with requisite skills, capital for infrastructure, water availability and atmospheric pollution. Broader socio-economic considerations highlight the cyclical variations in the coal industry. Environmental factors include the capacity of the airshed and watershed to assimilate pollutant emissions, the despoliation of land by mining, and long term biophysical changes to the environment. Social preferences lead to political pressures and government must respond by selecting policies from among the options available. The role of public institutions is fundamental to achieve trade-offs where traditional market mechanisms are unsuccessful. The CRES study examines all these aspects and its report is published as 'Resource development and environmental issues: opportunities and constraints in the Hunter region'.

This monograph assesses the effects of coal mining and related activities on the air quality of the Hunter Region. It attempts to identify existing problems, to predict future impacts and to propose policy directions. Emphasis is placed on the maintenance of air quality levels which provide acceptable risks to the community for protection of public health and welfare.

A.J. Jakeman
Acting Head

CONTENTS

Foreword vii
Figures xi
Tables xiii
Preface xvii
Summary xix

SECTION I

The general problem and approach 1

1 Introduction 3
Background 3
Resource development and impacts 5
Overview of the air pollution problem 6
Outline of the monograph 12

2 The assessment approach 19
Introduction 19
Risk assessment 20
Modelling the risk system 23
Major problems of performing a risk assessment 27
A simplified risk assessment procedure for the Hunter Region and other studies 31

SECTION II

Specific air pollution problems 33

3 Air pollution from mining activities in the Upper Hunter Region 35
Introduction 35
Effects of dust 35
Modelling particulate pollution 39
The environmental survey 41
Demographic results 43
Quality of life results 43

Quality of environment data 50
Health background data 67
Dust, noise and trucks—three environmental problems in detail 67 -7[illegible]
Effectiveness of the survey 76
Major findings 77
Recommendations 79

4 Air pollution in the Upper Hunter Region due to large point sources 81
Introduction 81
The effect of sulphur dioxide emissions 82
The effect of other emitted air pollutants 104
The expected future air pollution levels due to Liddell power station in different meteorological conditions 108
Future air quality levels due to additional large point sources 113
Conclusions 126

5 Air quality in Newcastle and the effects of meteorology 129
Introduction 129
Air pollution levels in Newcastle 132
The effect of meteorological change on air pollution levels 139
Worst case scenarios 145
Conclusions 149

6 Major industrial sources in the Lower Hunter Region 153
Introduction 153
The industrial sources 153
Sulphur dioxide levels 156
Fluoride levels 160
Kurri Kurri data 162
Tomago data 164

7 Pollution from mobile sources 167
Introduction 167
Methodology 168
The pollutant dispersion models 169
The Larsen model 170
Simulation approach 172

The data 174
Simulation scenarios 178
Simulation results 179
Sensitivity of the results 186
Environmental air quality standards and human health 187

SECTION III

Policy approaches to air pollution control 191

8 Air pollution management in the Hunter Region 193
Introduction 193
Policy options in air pollution control 193
The costs and benefits of air pollution control 201
Applicability of options to air pollution control in the Hunter Region 204
Solutions based on mixed policy instruments 210
Conclusions 219

SECTION IV

Conclusions and recommendations 221

9 Conclusions 223
Air quality conclusions 223
General conclusions on methodology 230

10 Recommendations 233

Appendixes 239
I Dose-damage threshold information 239
II Institutional framework for environmental control and planning 250
III Environmental survey questionnaire 258
IV Dustfall levels 263
V Statistical models 270
VI Mathematical models for atmospheric dispersion 279
VII The CRES model for urban air pollution levels 287

References 293
Abbreviations 305
Index 307

FIGURES

1	The Hunter Region: location of major towns and development	4
2	The framework for assessing environmental risk	22
3	The risk system and its component subsystem types	25
4	Schematic diagram showing likelihood of dosage to receptor areas	29
5	Schematic diagram showing mean and standard error only of dose from Fig. 4	29
6	Schematic diagram showing the likely range of impacts as the bounds of dosage change	30
7	The extent of existing and proposed open cut collieries in the Upper Hunter Region	37
8	Map showing localities surveyed	42
9	The degree of upset versus the degree of notice	56
10	Attitudes towards dust versus levels of dustfall experienced	69
11	Perception of dust versus levels of dustfall experienced	69
12	Positions of meteorological and sulphur dioxide monitoring stations	83
13	Monthly mean measured concentrations at six monitoring sites	85
14	Variation of monthly energy consumption for Liddell power station	86
15	Cumulative frequency distributions for Glennies Creek SO_2 data	87
16	Wind roses for Liddell meteorological station	90
17	Wind roses for the Mt Arthur meteorological station	91
18	Diurnal variation of monitored concentrations and influential windspeed direction	92
19	The comparison of observations for winter 1980	98
20	Weekly levels of total fluoride concentrations	107
21	Predictions of hourly SO_2 levels using the trapping model	115
22	Contours of the maximum SO_2 levels	120
23	The location of the Upper Saddlers Creek, Ponds Creek and Whites Creek sites	122
24	A third power station at Upper Saddlers Creek	123
25	A third power station at Ponds Creek	124
26	A third power station at Whites Creek	125
27	Newcastle area with air pollution monitoring network	130
28	Average annual mean acid gas readings 1959–81	131
29	Average maximum acid gas readings 1959–81	131
30	The mean insoluble dust deposition rates at 20 Newcastle stations for 1960–80	132

31 The mean concentrations at seven stations 136
32 Maximum 24 hour readings 137
33 Comparison of observed and predicted maximum acid gas levels at Watt St station for 1959–81 141
34 Mounter St station 142
35 City Hall station 143
36 Variation in K-factors for each of Watt St, Mounter St and City Hall acid gas data sets 143
37 The cumulative frequency distribution for Watt St acid gas data in 1981 144
38 Variation of the meteorological factor for the years 1951–81 146
39 The location of power stations and aluminium smelters in the Lower Hunter Region 155
40 The distribution of hourly wind speeds for 1980 and 1981 172
41 Major steps in the simulation algorithm 175
42 Average diurnal variation of Liddell wind speed data for 1980 and 1981 177
43 Relative concentration of dispersed pollutant from a roadway emission source 182
44 Average diurnal variation of maximum concentrations of nitrogen oxides in Singleton 183
45 Average diurnal variation of maximum concentrations of nitrogen oxides in Singleton 184
46 The usual EIS approach for air quality impacts 197

FIGURES IN APPENDIXES

1 Location of dustfall gauges and populations surveyed in the Broke area 265
2 Location of dustfall gauges and populations surveyed in the Maison Dieu area 266
3 Location of dustfall gauges and populations surveyed in the South Muswellbrook area 267
4 Location of dustfall gauges and populations surveyed in the Ravensworth area 268
5 Location of dustfall gauges and populations surveyed in the Warkworth area 269
6 Cumulative frequency distribution for daily acid gas levels at Watt St for 1981 271
7 Cumulative frequency distributions for data at Glennies Creek on a lognormal scale 275
8 Cumulative frequency distributions on an exponential scale 276
9 Summer and winter dispersion for two different plume rise assumptions 282

TABLES

1	Significant industry and emission types for the Hunter Region	7
2	Rough estimates of emission loads from Hunter Region development excluding coal mines	12
3	USEPA air quality standards for particulates	36
4	Emission factors for Hunter Valley coal mines	40
5	Response statistics for the surveyed locations	44
6	Demographic data	46
7	Quality of life data	48
8	How respondents rated their existing location with their previous location	50
9	Environmental problems which 'annoy a lot'	52
10	Environmental problems which are 'noticed frequently'	52
11	First five problems by ranking	54
12	The ranking of the top categories	57
13	Statistical relations between the degree of upset and the degree of notice	57
14	Directly-affecting environmental problems	58
15	First five most-experienced problems	60
16	Mechanisms for the directly-affecting problems	60
17	Action taken against the directly-affecting problems of Table 12	62
18	The possibility of solving existing environmental problems	62
19	Delegation of responsibility to solve existing environmental problems	64
20	Devices used to counter environmental problems	64
21	Sources of dust, noise and trucks in the Upper Hunter Valley	68
22	Location groupings for various environmental problems	70
23	Contingency tables for attitudes and perception for the environmental problem of dust	71
24	Contingency tables for attitudes and perception for the environmental problem of noise	73
25	Contingency tables for attitudes and perception for the environmental problem of trucks on roads	74
26	Contingency tables for attitudes and perception for the problem of trucks within a mining region	75
27	SO_2 record lengths and monitoring stations	85
28	Comparison of observed maximum SO_2 with estimated values	88
29	Mean monthly wind speeds for Liddell	94

30 Estimates of maximum SO_2 levels for four stations SE of power station 95
31 Estimates of maximum SO_2 levels for two stations NW of power station 96
32 Comparison of model predictions and statistical estimates for maximum hourly SO_2 values 97
33 Ambient air quality standards for SO_2 100
34 Maximum SO_2 levels at Ravensworth and McInerny's 101
35 Concentrations of short-term exposures producing 5 per cent injury to vegetation 103
36 Maximum expected levels of oxides of nitrogen, particulates, and fluorides at McInerny's Farm 105
37 Comparison of hourly SO_2 readings above 10 pphm and the inversion readings at Williamtown 111
38 Inversions from Williamtown records 1980 and 1981 111
39 Number of 0900 hours inversions at Williamtown 113
40 Number of 2100 hours inversions at Williamtown from 1963 to 1982 in height classes 114
41 Stack characteristics and emissions used to simulate Bayswater power station emissions 116
42 Newcastle monitoring stations 134
43 Air quality standards used as guidelines by the SPCC 138
44 Worst case scenarios with present and projected changes in acid gas emissions 147
45 Comparison of predicted and observed suspended matter data 148
46 Worst case scenarios with present and projected changes in suspended matter emissions 150
47 Rough estimates of SO_2 emissions from major sources in the Hunter Region 154
48 Data sets for power stations south of Newcastle 157
49 Number of SO_2 levels above 5 pphm for power stations 158
50 Maximum SO_2 levels, in pphm, for power stations 158
51 Fluoride effects 161
52 Kurri Kurri gaseous fluoride data 163
53 Fluorine in vine leaves 164
54 Monthly average gaseous fluoride levels near Tomago 165
55 Traffic counts in Singleton 176
56 Light duty vehicle emission rates 176
57 Exhaust emission rates for heavy duty diesel powered vehicles 178
58 Vehicle emission factors and traffic counts 180
59 Ambient median and maximum 1 hour pollutant levels for Singleton from the ATDL simulation 180

60 Ambient median and maximum pollutant levels as 8 hour averages for Singleton from the ATDL simulation 181
61 Ambient maximum pollutant levels as 1 hour averages for Singleton from the GM simulation 181
62–64 Scenarios for ambient median and maximum pollutant levels 185–186
65 Summary of air quality standards for nitrogen dioxide 188
66 Summary of air quality standards for carbon monoxide 188
67 Air pollution control benefits in 1978 203
68 US air pollution abatement and control expenditure 203
69 Air pollutants of concern in the Hunter Region 205
70 Different model types 208
71 Performance measures that can be calculated by each model type 210

TABLES IN APPENDIXES

1 Sulphur dioxide and suspended particulates damage criteria 241
2 Fluoride damage criteria 242
3 Nitrogen dioxide damage criteria 244
4 Oxidants (expressed as ozone) damage criteria 247
5 State Pollution Control Commission (NSW) objectives 248
6 Representative dustfall levels for locations surveyed 263
7 Values of dispersion parameters 284
8 Hourly values of the parameter C/C 285
9 Estimates of K for wind speed 290
10 Comparison of estimated maxima and observed maxima for acid gas data 291

Preface

The authors would like to sincerely thank those people who have contributed to various aspects of the project while working in CRES. We are particularly indebted to Neil Daly, Jeff Butt, John Taylor, Alison Daly, Mark Greenaway, Tony Bayes and Bettye Dixon.

Many workers from other institutions provided welcome discussions and comment and we are especially grateful to the following: Howard Bridgman (University of Newcastle), John Chambers and David James (Macquarie University), Michael Dean and Tony Mitchell (State Pollution Control Commission), John Hails (Environmental Services, CSR), John Hannan (NSW Coal Association), and Tio Ping Hing (Electricity Commission). We are also indebted to Jetse Kalma (CSIRO) and Paul Steele (University of Colorado) for their detailed comments on a draft manuscript.

Extensive data sets were provided by the State Pollution Control Commission, the Electricity Commission, the Bureau of Meteorology, Newcastle City Council's Health Division and the NSW Coal Association.

We also appreciate the expert preparation of the manuscript provided consistently by Janine Corey and Debbie Wattam and the editing of Suzanne Ridley and Gordon Sheldon.

A.J. Jakeman
R.W. Simpson

Preface

The authors would like to sincerely thank those people who have contributed to various aspects of the project while working in CSIRO. We are particularly indebted to Neil Duus, Jeff Burt, John Taylor, Albert Ong, Mark Greenaway, Tony Evans and Bettye Dixon.

Many workers from other institutions provided welcome discussions and comment and we are especially grateful to the following: Howard Bridgman (University of Newcastle), John Chambers and David Jones (Macquarie University), Michael Dunn and Tony Mitchell (State Pollution Control Commission), John Hails (Environmental Services, CSR), John Hannan (NSW Coal Association), and Yiu Ping Hung (Electricity Commission). We are also indebted to Jose Kalma (CSIRO) and Carl Steele (University of Colorado) for their detailed comments on a draft manuscript.

Extensive data sets were provided by the State Pollution Control Commission, the Electricity Commission, the Bureau of Meteorology, Newcastle City Council's Health Division and the NSW Coal Association.

We also appreciate the expert preparation of the manuscript provided conscientiously by Jeanne Corry and Debbie Watson and the editing of Suzanne Ridley and Gordon Sheldon.

A.J. Jakeman
R.W. Simpson

Summary

Introduction

Development of the black coal resource base of the Hunter Region will continue given the opportunities that open cut mining provides for earning export income, for cheap electricity generation and for use in energy intensive industries. The Centre for Resource and Environmental Studies (CRES) began air pollution studies of the region in 1982 to identify existing problems, to predict future impacts and to propose policy directions for maintenance of air quality levels which provide a low risk to public health and welfare. This monograph reports the results of these air quality studies. The work forms part of a wider project undertaken by CRES to evaluate the overall effect of resource development in the Hunter Region. The emphasis is on identification of the constraints to and opportunities for development within a public policy framework.

Air pollution activities in the Hunter Region

The major activities which lead to significant releases of air pollutants in the region are open cut coal mining and electric power generation in the Upper Hunter Region; aluminium smelting and electric power generation in the Lower Hunter Region; secondary industry in the Newcastle port area; and heavy vehicular traffic in Muswellbrook, Singleton, Maitland and Newcastle. The major pollutants of concern are dust and noise from open cut mining operations; sulphur oxides, nitrogen oxides, fluorides and particulates from power stations, smelters and other energy-intensive industries; and nitrogen oxides from vehicles. Ozone levels are sometimes high in Newcastle and there is a localised lead problem at Boolaroo. There is no evidence to suggest acid rain is a significant problem at present.

The assessment approach

Two types of problems arose in performing the air quality assessment: information limitations specific to the Hunter Region and methodological limitations related generally to the status of assessment techniques.

Data restrictions arose from limited emissions information and inadequate ambient pollution and meteorological monitoring. Only average emission figures are available and these are subject to considerable uncertainty. Pollution data mainly suffer from having been recorded over too short an historical period, from considerable sampling and/or measurement error, from not being specific enough as to its component compounds and indeed some pollutants were not measured at all. Meteorological data tend to be recorded too infrequently and are usually not available close enough to the assessment area of interest.

Most of the international effort on air pollution prediction has concentrated on deterministic modelling. The main feature of this approach is that it determines ambient air pollution concentrations from source emission information and meteorological data using mathematical formulae which implicitly assume both a precise knowledge of all complex relationships and an access to data inputs with a high degree of reliability. Consequently, traditional deterministic models can be effective when predicting long-term mean pollution concentrations in the environment but tend to perform poorly when predicting short-term extreme pollution episodes. The latter are of primary concern in the Hunter Region and indeed throughout Australia.

New methodologies were developed during the course of the regional air quality studies to match modelling strategies to assessment objectives and to compensate for limitations in information. The general approach was based upon the concept of risk, defined as the probability value of an undesirable event and its consequences. A simplified risk assessment procedure was devised which aimed at predicting the frequency of occurrence of the full range of pollution levels and relating this to a range of air quality criteria designed to protect public health and welfare.

Statistical models were developed to enhance pollution data sets with missing recordings and to infer results for shorter time averages. These models predict pollution concentration in distributional form from a limited time series of pollution data only. Hybrid models were developed to predict the upper percentiles of the distribution of short-term pollution concentrations from emission and meteorological inputs. They combine the attractive features of deterministic and statistical models by allowing for prediction from causal inputs but using the statistical component to account for the effects of uncertainty.

A feature of the methodology is that it allows simulation of the effect of changes in meteorological regimes from year to year. This is an important consideration for two reasons: first, historical pollution records may be less than a few years' duration; and second, meteorology alone may account for significant fluctuations in pollution levels, for example, up to a factor of three within a thirty year period in the Newcastle airshed.

An environmental attitudinal survey method was also devised to quantify risk from those pollution problems such as dustfall and noise which constitute a loss of amenity. The method ranks perceptions and attitudes to the problems of concern among a general range of pollution problems and among other practical problems. It also attempts to quantify those threshold pollutant levels at which significant loss of amenity is incurred. Analysis of the survey results for communities on the fringes of coal mining activity supports the present use of the State Pollution Control Commission's interim criterion for assessing loss of amenity. However, it is possible that loss of amenity occurs at a threshold below the criterion.

Results

Air quality in the Hunter Region is generally acceptable at present in that there is not likely to be any detectable adverse effects on the population in the long-term, given the current status of epidemiological information. However, short-term concentrations of sulphur oxides, nitrogen oxides and particulates may be sufficiently high in parts of the region to warrant occasional concern, especially for those in the community who suffer bronchial and other respiratory problems. The major perceived air quality problem at present is the loss of amenity incurred by some populations suffering excessive dust fallout from open cut coal mining operations. There is also a high localised but serious lead problem at Boolaroo.

To avoid significant increases in pollution levels in the future, the location, type and level of control on new development must be chosen carefully. This seems to have been achieved overall with recent coal-related development. The Tomago aluminium smelter's fluoride emissions do not appear to be presenting an additional impact on the Newcastle airshed. The extension of the Kurri Kurri smelter is not expected to increase fluoride emissions significantly due to controls on the bakehouse. The siting of the Bayswater power station appears a good choice on air quality grounds. On the other hand, the environmental problems associated with open cut mining need special attention. A plethora of monitoring and modelling exercises needs to be carried out to assess any new major development proposals. In the next section the associated policy recommendations have been framed which will illuminate the important deficiencies and uncertainties revealed by the regional assessment.

Policy points

Pollution control

- There should be a further analysis of cost-effective policy instruments to provide incentives to polluters to reduce emissions. Initial analysis suggests there is a reasonable likelihood that new control instruments can be successfully integrated within the present regulatory system. The remaining analysis needs to concentrate on simulating the behaviour of pollution markets and calculating transaction costs. Such exercises would be relatively inexpensive and of national relevance.
- In particular, a compensation scheme should be (a) established immediately to offset the loss of amenity suffered by some communities near coal mines; (b) investigated for residents suffering high lead pollution levels near Boolaroo; and (c) investigated for affected crop owners if fluoride levels increase significantly.
- Pollution predictions should delineate the potential range of impacts and their probability of occurrence rather than rely on average values. This requires the use of stochastic methodologies and incorporation of the effects of fluctuations in long-term meteorology on air pollution levels. This is especially important for the preparation and assessment of Environmental Impact Statements.
- A central data bank should be established and administered with sufficient powers to collect and house all relevant environmental data. This would improve the accessibility of data and encourage the assessment process. Data are at present too fragmented among the State Pollution Control Commission, polluters and other monitoring agencies.
- A survey of selected population(s), not necessarily in the Hunter Region, subjected to annual average dustfall of between 2g and 4g/m^2/month could be used to refine the State Pollution Control Commission interim dustfall criterion of 4g/m^2/month.
- To ensure the protection of public health, it is important to obtain a satisfactory measure of the levels of suspended particulates in areas subjected to high dustfall. Dichotomous sampling is recommended.
- Noise levels should be monitored in areas affected by industrial noise like Maison Dieu, Ravensworth and Broke.

Monitoring and modelling policy

- Further study is needed to estimate the frequency and heights of meteorological inversions between Singleton and Muswellbrook together with the monitoring of sulphur dioxide maxima and nitrogen oxides for the calibration of a trapping model of pollution.

- When Bayswater power station becomes operational a monitoring exercise similar to that undertaken for Liddell is recommended to calibrate a basic dispersion model for that source.
- A spatially intensive monitoring exercise should be undertaken in the Newcastle area to determine the relative proportions of acid gases. If nitrogen oxides are significant contributors then separate monitoring of sulphur dioxide and nitrogen oxides should be implemented continuously.
- Continuous wind monitoring closer to Newcastle is recommended because of the sensitivity of air quality levels to meteorological change.
- A study is required to estimate the effect of long range transport of acid gases from sources outside Newcastle.
- Future acid gas producing development in the Lake Macquarie, Maitland and Cessnock areas should be treated with caution.
- Continued ambient, vegetation and forage monitoring to assess the effects of fluoride emissions is warranted near the two aluminium smelters.
- A short period of monitoring to assess the levels of nitrogen dioxide from motor vehicles in the Maitland area is recommended.
- Improved forecasts of suspended and deposited particulates are needed to determine the extent of buffer zones and the requisite level of pollution control on mining operations. Special intensive studies are required to determine emission factors. Extensive data collection over a three-to-four year period is needed to build up a sufficient data base so that a useful model can be developed.

SECTION I

The general problem and approach

1

Introduction

Background

The Hunter Region of New South Wales is undergoing increased development of its black coal resources and associated dependent industries. The aim of this monograph is to provide an assessment of the impacts of that development on the region's air quality. This section provides some general background to the region.

The region derives its name from the Hunter River and its valley which lies on a northwest-southeast axis draining to the sea at Newcastle about 100 kilometres north of Sydney. Being climatically temperate with good rainfall, and with fertile soils especially along the alluvial flats of its valley, it is not surprising that settlement began here to the north of the parent Sydney colony in the early 1800s. The Hunter Region is a NSW planning division of about 30,000 square kilometres and has a total population of 462,000 according to figures released from the Australian Bureau of Statistics Census taken in 1981. Fig. 1 shows the subdivision of the region on the basis of local government areas into the Upper and Lower Hunter Subregions. The Upper Hunter is predominantly rural containing the major towns of Singleton (population 9,572), Muswellbrook (8,548), Scone (3,950), Aberdeen (1,410) and Denman (1,122). The Lower Hunter Region is more urbanised and comprises the industrial city port of Newcastle (135,194), Lake Macquarie City to the south (153,500), the river town of Maitland (39,936) and the old underground coal mining centre of Cessnock (16,916) and the area around the Alcan smelter at Kurri Kurri (12,794). Fig. 1 also shows the location of major development in the region including the sites of aluminium smelters and power stations, the major industrial area of Newcastle and the areas of open cut coal mining.

While black coal is the exclusive mineral resource of the region (exports valued at 900 million dollars in the financial year July 1982 to June 1983), its significance as the target of national development can easily be appreciated when it is realised that the region contains well

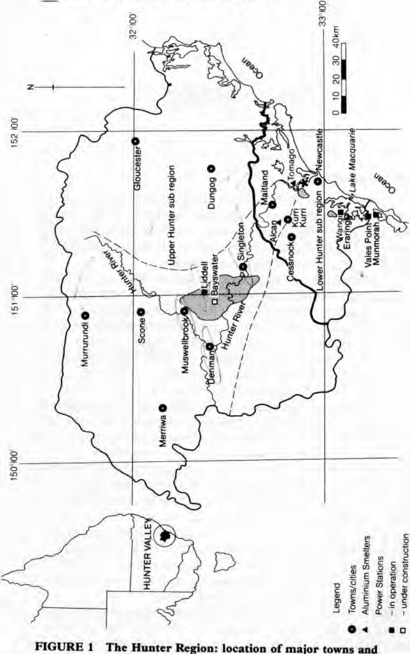


FIGURE 1 **The Hunter Region: location of major towns and development**

over 20 per cent of Australia's *in situ* proven reserves. The Joint Coal Board, for example, has estimated that 8,854 million tonnes of coal are economically recoverable with existing technology. In the financial year 1983–84 (July–June), 43 million tonnes of raw coal were mined in the Hunter, compared to 35 million tonnes in 1981–82 and 29 million tonnes in 1979–80. About 15 million tonnes in 1981–82 emanated from the more profitable open cut mining areas concentrated along the Upper Hunter river valley between Singleton and Muswellbrook. However the proportion of coal emanating from the more profitable open cut areas can be expected to increase in the long term. In 1982–83 and 1983–84 over 20 million tonnes were produced from the open cut areas of the region. The planned capacity of open cut operations could even yield 40 million tonnes in the late 1980s if markets are found.

In 1983–84, about one-half of the coal mined was exported through Newcastle, another one-third was supplied to the region's five thermal power stations and the remainder was used for steel making in Newcastle and other smaller energy-intensive industries. The high coal consumption of the power stations is indicative of the fact that most (about 80 per cent in 1983–84) of the electricity requirements for NSW are generated within the region.

Major industries in the rural sector are beef and dairy cattle, poultry, sheep and wool, wheat and grains, vegetables and fruit, grapes, fishing and forestry. In terms of value of rural commodities produced, the beef, dairy and poultry meat industries are dominant, each contributing about one-quarter of estimated gross rural value. The per capita value of agricultural commodities produced in 1982–83 was 453 dollars, compared to 1,765 dollars for manufacturing and 2,070 dollars for coal production (Hunter Valley Research Foundation 1985).

In summary, coal is the basic resource sustaining development in the Hunter Region. The coal is mined for export, for NSW electricity generation and for secondary industry requirements. In direct terms, the value of this resource development far exceeds that of other primary industries. Indeed, the role of coal as the basis for industrial development as well as for direct export earnings has elevated the Hunter Region to prominence on the national stage and makes regional changes a direct concern to federal and state governments alike.

Resource development and impacts

The public choice dilemma facing the Hunter Region is that on the one hand it has substantial energy resources and that it has been New South

Wales government strategy for almost a decade to develop those resources not just for export but to attract energy-intensive industries to the region. The strategy has partly been a response to easing the high unemployment, and arresting the decline of industrial activity, within the state and region. On the other hand, there has been no comprehensive assessment of the potential social and environmental effects of continuing resource development within the region. In responding to the challenge of providing a useful regional assessment, the approach at the Centre for Resource and Environmental Studies (CRES) was first to identify major points of interaction of coal production with the environment, social values, political priorities, international economic forces and so on and then to consider the public policy issues which arose. This was carried out within the context of public choices between options and estimates of the limits to the growth of the resource development.

Direct supply factors which were seen to constrain potential were the coal resource base itself, the availability of labour with the requisite skills and capital in appropriate forms. Demand factors, which are more dependent on broad socio-economic conditions, are the domestic and export markets where Hunter coal is traded. Environmental factors include the availability of water, the capacity of the airshed and watershed to assimilate pollutant emissions, the despoliation of land by mining and long term biophysical changes to the environment. Social preferences need also be considered where attitudes lead to political pressures and choices can be made among the options presented. This monograph presents the CRES response to the air quality constraints to resource development in the Hunter.

Overview of the air pollution problem

With the type of industry and development outlined at the end of the first section, the major air pollution emissions in the region can easily be defined. Basically they comprise: dust and noise from open cut mining operations; sulphur dioxide, particulates, fluorides and nitrogen oxides from power stations, smelters and other industry; and nitrogen oxides, carbon monoxide, hydrocarbons and particulates from transport. Acid rain is not yet perceived as a significant problem although a joint (State Pollution Control Commission—Electricity Commission—University of Newcastle) study was commenced in 1984 to investigate the potential for acid rain problems (see Rothwell *et al* 1984). The vehicle population density is low enough at present in the region to avert the formation of photochemical smog in general but ozone levels are sometimes high in Newcastle. Lead particulate concentrations are also sometimes high in one small area, probably due to local industry.

Table 1 gives a summary of the major types of emissions which emanate from industrial activity and vehicular traffic. Emissions known to occur in negligible quantities are not included. However accurate emission inventories for coal-based resource developments in the Hunter Region are not available. Bridgman and Kalma have surveyed a number of industries (*see* for example, Bridgman *et al* 1983) to obtain more comprehensive information. Supplementary material is also available from Environmental Impact Statements, particularly for larger developments, and from State Pollution Control Commission information. From these sources we have compiled rough estimates of emission loads for stationary sources in the Hunter Region and these are presented in Table 2.

TABLE 1 Significant industry and emission types for the Hunter Region

Area	Emission source (Location)	Emission type
Upper Hunter Region	Open cut coal mines (see Fig. 1)	particulates leading to deposited and suspended dust, noise
	Power stations (Liddell)	sulphur dioxide, fluorides, particulates, nitrogen oxides
Newcastle	General energy-intensive industries (eg BHP, Kooragang Island), Vehicles	sulphur dioxide, nitrogen oxides, carbon monoxide, particulates (inc. lead), ozone, noise
Lower Hunter Region	Power stations (Eraring, Munmorah, Vales Point, Wangi)	sulphur dioxide, fluorides, particulates, nitrogen oxides
	Aluminium Smelters (Kurri Kurri, Tomago)	fluorides, sulphur dioxide, particulates
Major through traffic towns	Vehicles (Singleton, Maitland, Muswellbrook)	Nitrogen oxides, carbon monoxide, particulates, noise

It is impossible to present even rough estimates for particulate (dust) emissions from open cut coal mining activity since emissions vary according to the type, scale and location of each operation. Suffice it to say that particulate emissions from coal mines far outweigh those produced by power stations. Dust pollution from the open cut mining of coal is one of the most significant emission problems, at least in terms of its nuisance effect. It arises from operations which involve the removal of topsoil, overburden and coal, drilling and blasting, handling, transport especially along unsealed roads, and not least, from the exposure of bare areas to wind. While most of the dust fallout occurs close to the mine face there are many rural properties and some small settlements on the fringes of mining lease areas where the inhabitants suffer the inconveniences of dust pollution. Noise from mining operations is also of some concern. In order to gauge the perceived magnitude of the nuisance effect of dust and noise pollution, an environmental attitude survey was undertaken in the vicinity of lease areas. The results which will be reported in Chapter 3 show a strong correlation between the degree of annoyance and the level of dustfall.

It seems unlikely for populations near open cut coal mines that there are any significant direct health risks which arise from the breathing and deposition of fine dust particles in the inner parts of the lung. However, this conjecture requires verification. It is only recently that dust pollution has begun to be measured on a limited scale in the valley by hi-volume samplers which record ambient concentrations in air rather than the traditional and less expensive method of measuring fallout in a deposit gauge. The latter is reasonably suitable for measuring levels of disamenity. On the other hand, it is the heavier particles which fall out more quickly so that deposit gauges are not appropriate for obtaining concentrations of fine dust particles even if their contents were analysed for particle size. It is envisaged that the State Pollution Control Commission (SPCC) of New South Wales will eventually move to use, and encourage industry to use, dichotomous hi-volume samplers which differentiate between particles above and below the inhalable threshold diameters. For example, 15 microns is the threshold below which particles can be inhaled whereas 1 micron is the threshold below which particles can be lodged in the innermost parts of the lung.

As Table 2 implies, an important air quality impact requiring investigation arises from the current proliferation of thermal power stations in the region. In March 1982 there were only four power stations, Liddell in the north-west and Wangi, Munmorah and Vales Point in the south-east, having a total generating capacity of 6,700 megawatts (MW). Since then the first stage of Eraring with 660 MW has come on line. The second, third and fourth stages, also of 660 MW capacity each, were designated for completion in December 1982, June 1983 and February 1984, respectively but are running well behind those schedules. Additionally, the construction of the Bayswater power station is under way and operation is scheduled to commence in four 660 MW stages between 1985 and 1987. These new stations increase generating capacity by almost 80 per cent over early 1982 levels.

The largest emission impact from power stations is likely to come eventually from Liddell and Bayswater which will operate within a few kilometres of one another in the Upper Hunter. In contrast to the power stations in the Lower Hunter which also generate high levels of sulphur oxides, nitrogen oxides and particulates, the emissions of Liddell and Bayswater will impinge on areas where suspended dust levels are concentrated from open cut coal mining areas. Fortunately, the concentrations of the most significant gaseous pollutants, sulphur dioxide, nitrogen oxides and fluorides, measured in the environs of Liddell, were sufficiently low under 1980–81 conditions to protect human health and provide negligible economic damage to vegetation and materials. Sulphur dioxide concentrations reached an observed maximum of only 0.022 parts per million (ppm) in 1981 for a 24 hour average compared, for example, to the fairly conservative desired Canadian level of 0.06 ppm. However, it is the short-term cumulative effects of the gaseous pollutants and/or the dust which are of concern. For example, sulphur oxide, nitrogen oxides and particulates together can have effects on human health, vegetation and materials which are worse than the sum of their individual effects. The knowledge of such synergism in fact has led to the specification of joint air quality standards for sulphur dioxide and particulates throughout many industrialised countries.

In addition, future levels may be exacerbated by two major factors. First, Bayswater is slightly larger in capacity and able to burn fuel of higher sulphur content than Liddell, and so will emit up to 1½ times more sulphur dioxide. When its increased stack height is taken into account it is possible that current air pollution maxima could, depending on wind conditions, increase up to 100 per cent over 1981 measurements. Second, the 1980–81 period over which data were comprehensively collected may represent atmospheric conditions favourable to the wide dispersion of point source emissions. Unfavourable conditions which lead to the trapping of pollutants occur under subsidence inversions. Analysis of subsidence inversion data since 1961 on the nearby coast at Williamtown shows firstly, that the 1980–81 period contained low frequencies of inversion conditions compared to the long-term average; and secondly, that it is not unusual to have long periods where the frequencies per month for twice daily recordings of inversions are up to eight above the average number of monthly occurrences.

The air quality issue which originally received the most media attention in the region was the potential for damage to the vineyards and other cropped areas of the valley by gaseous hydrogen fluoride from aluminium smelting. However, the high levels anticipated have not been realised and the risks of vegetation damage at present are low outside buffer zones. Dry scrubbing control technology was introduced completely at Alcan's Kurri Kurri smelter in January of 1982, and since then the high annual averages of hydrogen fluoride gas experienced in the late 1970s have fallen dramatically. The fluoride problem has also eased because the proposal to build a third smelter in the valley at Lochinvar lost financial support. However, the first of two stages of the state's second smelter at Tomago was commissioned in September 1983 and full operations began in October 1984. Additionally, Alcan commissioned an extension to their smelter in early 1985 making a new assessment of fluorides and their impacts on vegetation in the Hunter Region desirable.

Although the city of Newcastle is, if anything, experiencing a small decrease in industrial atmospheric emissions because of a winding down of its steel output, recordings indicate that it does have a significant acid gas problem. It is mainly related to sulphur dioxide emissions caused by the burning of sulphurous coal and oil in the heavily industrialised port area. However, it is possible that nitrogen oxide emissions from motor vehicles and industry also contribute significantly to the acid gas levels. While there is some argument over the reliability of recent measurements there is little doubt that concentrations of acid gas increased in 1981 and 1982, for example, despite a levelling off in source emissions. Depending on location, the annual mean of 24 hour average recordings in 1982 was reported to be close to the United States air quality primary standard of .03 ppm. It is clear that this problem also requires assessment.

Most of the coal transported throughout the region travels by rail. However, large quantities are taken over public roads to washeries or rail loading facilities. In 1981–82 for example almost one million tonnes were transported by road to power stations. The larger towns affected by through traffic are Muswellbrook, Maitland and Singleton.

Between the 6 am and 6 pm period heavy duty trucks daily traverse the Dunolly Bridge over the Hunter River at Singleton at a very high rate: between 8 and 9 am on one day in 1982 the rate was measured at one coal truck every 40 seconds and one service truck every 38 seconds. The daily total was around 1,767 trucks. It is possible that by 1995 this number may increase to over 3,000 assuming a 4½ per cent per annum increase in traffic volumes. Consequently, there would be an accompanying increase in vehicle emissions and noise levels. Unfortunately, there are no measurements available for monitored ambient concentrations of pollutants or noise resulting from vehicle emissions in the Upper Hunter Valley.

In summary, it is fair to say that at present the quality of the Hunter Region's atmospheric environment is not in as poor a state as in a number of other industrialised regions of the world. Annual average levels of pollutants do not seem to be exceeding ambient air quality standards such as those of the United States. We will use modelling to explore this further and consider the level of future development which may be possible yet still provide reasonable protection to public health and welfare. Some of the problems that are currently significant either constitute aesthetic nuisances in general, affecting the quality of life of small populations and causing indirect effects on health such as through added stress, or are short term in duration, potentially affecting members of the population with respiratory complaints. Because these arise in localised areas it should therefore be possible through careful planning or appropriate compensation arrangements to ease them. Perhaps a more marginal problem is acid gas pollution in Newcastle City, while potential problems are the synergistic effects of sulphur dioxide and nitrogen oxide emissions from power stations with dust from open cut mines, and fluoride emissions from aluminium smelters.

TABLE 2 Rough estimates of emission loads (thousands of tonnes/year) from Hunter Region development excluding coal mines (from Rothwell *et al* 1984 estimates, Saw, 1983, conversion factors, and SPCC, 1980)

Source	Sulphur oxides	Particulates	Nitrogen oxides	Fluorides (gaseous and particulate)
Electricity Commission Power Stations				
Liddell	20.0	6	31	.36
Wangi	1.5	1	5	.05
Munmorah	11.0	4	19	.22
Vales Point	14.0	4	19	.22
Eraring (full capacity)	27.0	7	38	.43
Bayswater (half capacity by 1986)	26.0	3	17	.19
Aluminium Smelters				
Tomago (full capacity)	21.3	—	—	.22
Kurri Kurri (full capacity)	13.1	—	—	.14
Broken Hill Pty Ltd	4.2	—	—	.09
Fertilizer plants	1.0	—	—	—
Other sources (combined by type)				
Brickworks	.8	—	—	.05
Chemical works	4.0	—	—	.08
Other metallurgical	3.5	—	—	0
Fuel burning	5.8	—	—	.004

Outline of the monograph

Although there is considerable uncertainty about future export levels of Australian coal it is difficult to foresee, given the current world energy situation, coal resource development plateauing at its present level. However, the boom period that was forecast just a few years ago has definitely not eventuated. This abatement obviously provides valuable breathing space to assess the cumulative risks of air pollution in the region from additional development and to weigh them against the economic benefits of such development. Such an assessment requires a range of actions ranging from the specific, such as additions and improvements to monitoring networks, through to the more methodological such as the application of modelling techniques for risk assessment. It is hoped that the study reported here takes a major step towards accomplishing this assessment and therefore provides sufficient information and recommendations to aid future decision-making in general and land use planning in particular for the Hunter Region. An outline of the work undertaken to achieve this is now in order. This is done in four sections. Section I includes this chapter which has described the region and the general problem and it will also provide the philosophy of our approach. Section II contains chapters on the individual problems whereas Section III considers possible policy approaches to air pollution control and Section IV presents the conclusions and recommendations.

Chapter 2 completes Section I by providing the framework upon which the regional air quality assessment is based. It begins with a discussion of environmental risk assessment as it should formally be applied and specifies the modelling requirements of an environmental system at risk. Ideally, any such model would be capable of reproducing the probability distribution of ambient concentrations in a given year. In this way, the number of times a year a specified pollutant level is exceeded can be extracted (health standards are written in this form), or the length of time a threshold is exceeded can be obtained (damages are calculated from such information). Of course, some health standards and damages require long-term averages of pollutant concentrations and obviously these can also be calculated from the probability distribution if necessary.

Fortunately, the risk assessment process can be simplified in the Hunter Region where there tends to be a safety margin between maximum ambient pollutant concentrations experienced and levels at which damage occurs. Consequently, models of the pollution dispersion process which are suitable for estimating risk in the Hunter Region should be able to predict maximum ambient concentrations adequately.

It is argued that a comprehensive approach to air quality modelling must also incorporate the effects of possible long-term meteorological fluctuations since different weather regimes over the years can produce quite different effects. Where possible, an analysis of the meteorological history of the area being modelled is undertaken and the calendar years are classified in an appropriate manner so that some idea of the frequency of occurrence of the different meteorological regimes can also be obtained. With this information, the air quality models yield, for a fixed emission input, an indication of the variability of ambient pollutant curves and their chances of occurring.

Section II contains five chapters which deal specifically with estimation of the risks from the individual problems indicated in Table 1. In particular, Chapter 3 treats the environmental problems resulting from the operation of open cut coal mines in the Upper Hunter Region. At present, there is too little meteorological and dust data available to successfully model either the dust deposition process or ambient dust concentrations (suspended particulates). There are similar problems with noise. However, it is not difficult to delineate current and potential problem areas and hypothesise the range of dustfall levels that these areas are likely to experience. It is more difficult, however, to do this for suspended particulates since very little monitoring of these has been undertaken.

Because the environmental risks from open cut coal mining are perceived to be more of an aesthetic concern than a direct health concern, at least in the short term, a survey was carried out to determine the attitudes of communities in the vicinity of mining leases. The environmental problems were rated in their order of perceived importance and where possible each was correlated with measurement data. The survey was also used to determine how the environmental problems compared in importance with other perceived problems. The results of this survey are also reported in Chapter 3. They provide a good appreciation of the impact of mining activity on the day-to-day enjoyment of populations on the fringes of open cut coal mining areas.

Chapter 4 considers the other major industrial operation in the Upper Hunter Region—electricity generation from the Liddell power station and that at nearby Bayswater which is presently under construction. It investigates the effects of sulphur dioxide, nitrogen oxides, fluorides and particulate emissions from the power stations on ambient concentrations and, in turn, the impact of those concentrations on target receptors in the Upper Hunter Region. Most of the monitored data available is for sulphur dioxide and covers the years 1980 and 1981 only. A statistical model is used initially to predict maximum expected sulphur dioxide values with respect to ½ hourly, hourly, 3 hourly, 8 hourly and daily time averages, a useful approach when observations are restricted but provide representative samples. The model assumes that an exponential distribution is an adequate representation of the air pollution data.

Only a rough estimate of the maximum of the statistical predictions and the location of this maximum can be reproduced using the usual physically-based dispersion models but not the frequency distributions, since these models tend to overpredict in the low to medium concentration range. Nevertheless, this is satisfactory since the threshold damage levels of dosage for individual pollutants are generally higher than these maxima. Therefore, while a limited number of violations of the more conservative air quality standards have occurred according to the statistical models, the risk to health, vegetation and materials is quite low for individual pollutants if the 1980–81 data base is representative of potential ambient pollution levels.

The possibility of cumulative effects among pollutants must also be considered, and while the relevant literature is scant and confusing in this regard, it points to areas of concern which indicate that the physical evidence should be monitored continuously. In addition to the potential for these combined effects of pollutants, it is also shown that ambient concentrations can vary widely from year to year with meteorological changes. For instance, the changes in the sulphur dioxide levels monitored by the SPCC in 1980 and 1981 are partly due to the differences in the wind speed regimes. However, the potential exists for even further significant increases in the upper percentiles of ambient levels if worse inversion conditions than those during 1980–81 are possible.

The chapter concludes with an assessment of the air quality likely to be associated with the establishment of a third large power station in the Upper Hunter Region. The analysis considers a number of alternative locations in the vicinity of the present power stations.

Chapter 5 best illustrates our approach to the estimation of risk from atmospheric pollution with a consideration of acid gas levels in Newcastle. The analysis is comprehensive because of the availability of long records of meteorological and pollution data. Apart from lead, acid gas is the most significant pollutant in the city area and is emitted by many energy-intensive industries burning sulphurous coal or oil.

A hybrid deterministic/statistical model is used to simulate the distribution of daily observations of acid gas at many city sites under prevailing meteorological conditions. A statistical model is also used to decompose the annual distributions of 24 hour averages into corresponding distributions of shorter term averages. The hybrid approach predicts average, median and maximum pollutant levels for desired time-averages under almost the entire range of annual meteorological conditions experienced since 1950. It shows that annual maximum levels of ambient concentrations can vary by a factor of two due to meteorological changes alone. Thus one can calculate the increase in emission strength allowance in the city for specified air quality criteria given the meteorological conditions in the area. Therefore industrial expansion can be planned up to a limit beyond which further controls, other than the present specification of the sulphur content of fuel burned, would need to be considered. Analysis of the meteorological history provides information useful for setting the air quality criteria with the requisite built-in safety margin. It indicates how often worst-case meteorological conditions may occur, and hence whether they are frequent enough and severe enough to be of concern.

Chapter 6 investigates the air quality and associated potential risks in the Lower Hunter Region. As with the problem in the Upper Hunter Region treated in Chapter 3, the major emission sources are also elevated point sources—from the Eraring, Munmorah, Wangi and Vales Point power stations and the Alcan and Tomago aluminium smelters; the latter also produce line source emissions from the roof vents.

The methodology applied in the Upper Hunter Region, however, would not be as successful if applied here because the data base for the ambient levels around the Lower Hunter power stations is comparatively scant. Therefore we refer to the results obtained by James *et al* (1983) who have studied the problem with a deterministic modelling approach. The addition of emission loads, with the Eraring power station and the Alcan smelter at full operational capability, are considered. The available pollution data base leaves many questions unanswered so that we outline steps that need to be taken to obtain a fuller assessment in the Lower Hunter Region.

Chapter 7 contains the final portion of Section II on the calculation of risks from specific developments in the Hunter Region. Here, the contribution of road transport vehicle emissions to air pollution is estimated in areas of concern. Attention is focused on the major towns subject to increasing levels of through-traffic from coal trucks. These are Singleton, Muswellbrook and Maitland. Unfortunately, there are no monitored data for ambient concentrations of pollutants in these towns. In order to identify the level of priority which should be given to the acquisition of such data, a simulation approach was adopted to predict current levels and to hypothesise future levels, the latter being dependent on an estimate of traffic growth and the introduction of further controls on emissions from motor cars in 1986.

The simulation results indicate that carbon monoxide and nitrogen oxides will be of most concern. Carbon monoxide levels are likely to remain below ambient air quality standards but nitrogen dioxide levels may exceed certain air quality standards. Again the results are obtained for a number of years characterised by substantially different meteorological behaviour.

In Section III, Chapter 8 of the monograph considers air pollution management in the Hunter Region. Current management is based almost entirely on regulation. In particular, Chapter 8 examines the use of economic instruments as an additional means of controlling air pollution since they offer incentives to developers to reduce their emissions of pollutants. And in theory this can be achieved at a lower overall cost than the pure regulatory approach. In particular, the contrast between the present regulatory policy of direct controls and those using economic incentives is considered in order to judge the feasibility of the latter policies in practice.

Section IV includes Chapters 9 and 10 and gives the conclusions and recommendations. This involves a summary of our findings and specific courses of action that should be undertaken. Chapter 9 notes current problem areas and, where the data base allows, the future constraints. Chapter 10 first specifies the monitoring requirements recommended for more careful assessment of the Hunter Region's atmospheric environment and its assimulative capacity. These relate to both pollution measurement and meteorological recordings. Chapter 10 also produces recommendations for analysing the potential integration of economic incentives into the present regulatory system.

The monograph contains numerous appendixes for those interested in looking at the finer details and the technical bases of our assessments. Appendix I is a review of dose-damage information obtained from what is considered to be the most reliable literature sources. It contains table summaries of the individual pollutants of concern in the Hunter Region, the concentrations and averaging times over which damage to health and welfare (vegetation, material damage) can occur, and the environmental standards of various countries. It also contains data on cumulative effects. This information is useful reference material for Chapters 3 to 7.

Appendix II outlines the institutional framework in New South Wales for environmental impact assessment and management, stressing the salient features of the various acts governing environmental protection. It also details the roles and underlying strategies of the Department of Environment and Planning (DEP) and the SPCC, as well as the requirements of developers and the facilities for public participation in the assessment process.

Appendix III reproduces the questionnaire used to perform our environmental survey as analysed in Chapter 3.

Appendix IV contains the dust data used to relate the perceived degree of nuisance to level of dustfall in areas affected by dust from open cut coal mining.

Appendix V contains details of the statistical models used to obtain distributional properties of ambient pollution concentrations throughout Section II. These models include the Larsen lognormal distribution and the exponential distribution and are useful for predicting concentrations over time averages different from that over which measurement takes place. They are also useful for building more complete distributions from data belonging to restricted but well-sampled periods.

Appendix VI presents the Gaussian plume models used to describe the dispersion of pollutants from elevated point sources in Chapters 4 and 6 and in Chapter 7 from line sources on a roadway. It provides details of the specific values of the model parameters used.

Appendix VII describes the hybrid deterministic/statistical modelling approach used particularly in Chapters 5 and 7. It shows how the approach uses deterministic models over their range of greatest applicability to predict points on a pollution distribution curve. The curves used have an assumed functional form which is only fitted over its reliable range.

2

The assessment approach

Introduction

Since their inception in Australia, environmental impact assessments have relied heavily on quantitative techniques to estimate the magnitude of specified impacts. This is especially true in assessing the quality of the atmospheric environment where prepared assessments have focused on the use of packaged computer models to predict pollutant concentrations over some set of averaging times and input conditions. Such models and their usages are typified by recent assessments of the impacts of Hunter Valley power stations (Electricity Commission of NSW 1979) and aluminium smelters (James B. Croft and Associates 1980).

As awareness has grown of the *complexity* of environmental systems and the *uncertainty* of their behaviour and the uncertainty in the data collected from them, the concept of *probability* of occurrence of events has assumed increased importance. This has led to attempts to apply probabilistic theories to the evaluation of environmental effects. The application of models to the calculation of frequency distributions of potential ozone as a guide to the formulation of oxidant controls (Daly 1978, 1979) and the statistical modelling of distributions of events (Simpson *et al* 1983) are specific responses to these general requirements.

In recent times the drive to employ probabilistic techniques has been formalised in the process of *risk assessment*. The term has been chosen to distinguish the process from impact assessment, and is described (Whyte and Burton 1980) as a means of extending the concept of environmental assessment. Environmental risk has been defined as 'the probability value of an undesirable event and its consequences that arise from a spontaneous natural origin or from a human action that is transmitted through the environment'. In mathematical terms, risk is the probability times the consequence of an event. Therefore, the difference between impact assessment and risk assessment is that 'impact assessments are concerned with events that are reasonably certain to occur, while risk assessment is concerned with events that may possibly occur'. It should also be stressed that 'the difference between certain and probabilistic events appears not in the nature of the events themselves but in the human understanding and description of the processes involved' (Whyte and Burton 1980).

Obviously, the first step in risk management is the identification of the state of knowledge and risks of the system under study. The other steps are quantitative estimation of the risk followed by evaluation of the risks with a view to decision making. This chapter deals mainly with the estimation and evaluation phases. Already some of the risks have been identified and the individual chapters in Section II will bring out deficiencies in the state of knowledge for the various problems.

Risk assessment

As will be discussed in Section III and Appendix II, two basic pollution control policies are in use in NSW; these are:

- the environmental management/standards approach; and
- the best practicable means approach.

The first approach is to help ensure that the effects of a development do not bring about violation of environmental standards or guidelines. In NSW the term 'guidelines' or 'criteria' is used rather than 'standards' since the latter infers that there exist legal requirements for compliance as occurs in the United States (US), for example. The most comprehensively documented example of the environmental standards approach is the legislative history of the US Clean Air Act amendment (US Library of Congress, Environmental Policy Division, 1974).

The best practicable means approach is less clearly defined than the standards approach and seeks to apply judgments framed within the context of each individual case. While the approach allows a degree of flexibility which is especially useful when sensitive receptors are absent, it is sometimes one which allows high benefits to outweigh environmental risks. The classic case cited by Whyte and Burton (1980) is the toleration of an industry with high pollution levels because it brings needed employment to a region. The approach is basically one-sided, concentrating on the costs of controls and the benefits of the polluting activity. It does not involve a methodology for assessing the associated environmental costs.

Each of these approaches deals with a particular aspect of the environmental management problem. The risk assessment framework depicted in Fig. 2 integrates the advantages of both. The framework in Fig. 2 is adapted from that of Whyte and Burton (1980). Application of it requires consideration of the state of knowledge and the risk characteristics in each of the four risk systems identified in Fig. 2. The objectives are to assign reliable estimates of the probabilities of risk for each.

Originally included within the framework of Whyte and Burton (1980) is the comparison of environmental risk against other societal risk. This aspect is omitted here for convenience as it is preferred to leave this non-environmental issue to others and make comparisons just with the level of alternative (environmental) risks. In fact, few attempts have been made to relate the literature on the perceived risks of technological hazard to the extensive literature on the risks of natural disorders (Covello, 1982). However, since the consideration of risk is relative, it would not be objective to omit evaluation of the risk elevated above natural levels. Clearly, the alternative risk systems component can be evaluated in the same way as the major risk system under consideration. Application of the risk assessment framework as an integrative philosophy also requires evaluation of how the probability of risk increases as benefits of the risk increase. These aspects are now discussed in more detail.

The risk system

The system of cause and effect for risk evaluation can conveniently be decomposed into a number of subsystems. Fig. 3 shows the breakdown into the following types:

- the polluting subsystem caused by human activity
- the mechanisms of transport which 'carry' the pollution to receptor sites
- the subsystem containing the receptors on which there is the eventual environmental impact.

The above categorisation is general. For example, in some systems, human activity may cause impacts directly. Certainly the breakdown is most relevant to atmospheric and aquatic systems.

To manage environmental risk effectively it is necessary to model successfully the processes linking the polluting human activity right through to the environmental effects. In this way, the intermediate and final effects of potential levels of human activity can be gauged. This modelling will often involve relating input or causal variables in a subsystem to output or response variables via a set of mathematical expressions or equations containing known and/or unknown system parameters. Clearly, once these unknown parameters are estimated satisfactorily, the response of the subsystem to a range of real or hypothesised

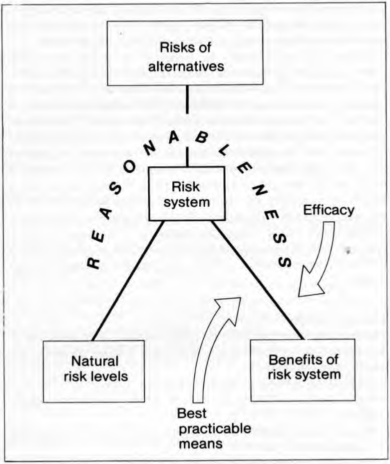


FIGURE 2 The framework for assessing environmental risk
Adapted from Whyte and Burton 1980.

inputs can be obtained. So in considering the transport model, the aim is to provide input scenarios to the impact system. As will be seen, successful modelling of the impact system yields some form of dose-response curves. These curves provide the basic information on the risk system, which, when interfaced with the benefits of the risk system, enables judicious choices of policy options for land use planning and the setting of desirable objectives for environmental quality.

Risk of alternatives

The risk of alternatives in the environmental assessment of plans for regional development is mainly concerned with: the choice of alternative locations for specific developments, and the choice of alternative developments for specific locations. These are land use options which can be evaluated as individual risk systems within the risk assessment framework. In Chapter 4, for example, consideration is given to various locations for the siting of a new power station in the Upper Hunter Region. No consideration is given in the monograph to the choice of alternative developments for specific locations since there is insufficient development pressure at the moment to make such considerations necessary.

Benefits of the risk system

Risks should be compared with their associated benefits. Thus, greater risks can be tolerated where there are greater benefits. The major difficulty with a risk-benefit comparison is that the benefits are usually more easily quantifiable than the risks. Even in cases where risks cannot be well quantified, a comprehensive risk-benefit analysis is worthwhile.

Natural risks

Natural risks are well covered by the methodology adopted in setting environmental quality standards. The procedure is to determine the distribution of natural levels of pollutants of concern and to select standards at some level which is not experienced in nature, and which provides a small probability of an adverse effect. The analysis in terms of dose-response relationships and frequency distribution of damages includes the natural risk system in the total assessment of risk.

Modelling the risk system

It is useful here to characterise the nature of the different risk subsystems so that the appropriate philosophical basis for a practical modelling approach can be adopted. The approach is statistically based and satisfies the requirements of risk assessment. It is expanded in a later section where deficiencies in the applicability of the current modelling procedures are also discussed and the application of the alternative statistical approach is described.

Nature of the risk subsystems

In order to categorise the commonality and differences among the three subsystems which make up the system for risk evaluation, it is pertinent to invoke the *ill-defined systems* concept formalised succinctly by Young

(1978). Basically, a system is ill-defined if the (mathematical) relationships linking system inputs, parameters and outputs (collectively called variables) possess a level of complexity which cannot be precisely investigated because it is difficult to perform the necessary planned experiments to obtain the data needed to identify all of those relationships. In the case of environmental systems, passive monitoring is often the only way data can be collected.

Therefore, the data from ill-defined systems have an associated level of uncertainty which arises not only from sampling and measurement errors but also from this passivity characteristic. The data are the inseparable product of a range of system mechanisms and, characteristically, the effects of individual mechanisms cannot be observed for long enough periods of time to be quantified with high precision. The interested reader is referred to Young (1978, 1982a,b) and Jakeman (1983, 1985a) where these concepts are illuminated by way of examples encountered in the modelling of environmental systems.

Within the above context, the *polluting component* of the risk system shown in Fig. 3 is usually well-defined. The relationships between variables may or may not be complex but they are generally capable of quite precise quantification since technological systems are designed to behave as they do. Therefore, predicting accurate model outputs of pollution source for input to the transport system often requires no special treatment here. The comments on modelling for risk assessment in the remainder of this chapter obviously relate, for the most part, to the more complex transport and impact systems. The exception to this is the mechanism of dust creation in coal mines where the polluting system, as will be seen, is ill-defined.

The ability to describe *physico-chemical transport systems* successfully within the environment varies. A fortuitous example is the transport of non-reactive pollutants down a river system. Transport within such a system can be explained quite satisfactorily for risk assessment purposes but certainly not exactly (Jakeman and Young 1980). However, the majority of transport processes possesses at least a poor level of definition. These especially include water and airshed systems when reactive pollutants are being considered.

In fact, one of the most ill-defined of these systems is the transport and deposition of inert dust from open cut coal mines. Butt *et al* (1982) provide the detailed reasons for the problems associated with precisely quantifying the complex relationships in such a system by experimen-

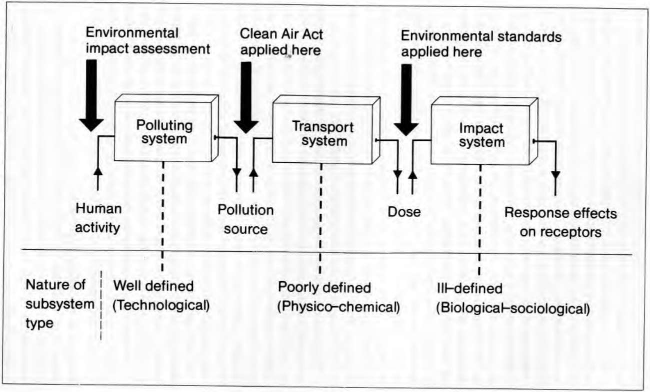


FIGURE 3 The risk system and its component subsystem types

tation. These reasons include the physical nature of the mine system as well as the sampling errors inherent in collecting relevant data.

On a more general note, it is widely accepted that the transport of any air pollutants under meteorological conditions of very low wind speeds, recirculations and fumigations cannot be satisfactorily described by currently available techniques of dispersion modelling (Feldstein 1976). Clearly, to include these mechanisms in a model would involve a level of mathematical sophistication that would be difficult to verify.

Almost invariably within the risk system, the *impact subsystem* suffers the weakest definition. Furthermore, for a given system, the definition will deteriorate as consideration of impacts changes from flora to fauna to the human species. Thus it is usually easier to describe, at least empirically, the relationships between dosage and effects in plants than in humans. However, even on plants, it appears difficult to conduct experiments which are representative of true field conditions. With animals and especially humans, the complexity of description increases because sociological effects impinge. The effects on humans, for example, are additionally influenced by their attitude to the pollutant. Alternative techniques for dealing with management of risk in some of these cases will be discussed in the case study in Chapter 3.

The construction of dose-response curves to describe the impact system and consequently set environmental standards as chosen points on such curves has concentrated mainly on humans. It therefore rests largely on evidence from epidemiological studies and to a lesser extent clinical experiments involving low dosages of a pollutant. A classic and comprehensive example involves the analysis and constant review of data for the setting of the British standard for ambient dust concentrations in underground coal mines (Jacobsen *et al* 1970 1971).

In the next section, the basis of our modelling philosophy is briefly described. While the general comments are applicable to the impact system, the emphasis is placed on the environmental transport system. It is especially in this area that modelling techniques, which are used from day to day to obtain information for environmental impact statements in particular and for environmental planning in general, can be comprehensively improved.

Basis of a modelling approach

A great deal of the modelling of environmental systems undertaken has shown little regard for the real objectives of the modelling exercises. At one extreme, models have been applied which *attempt* to reproduce reality in fine detail, thereby satisfying any objective that management may care to investigate. On the other hand, over-simplistic models have also been used to produce long-averaged predictions without accompanying statistics to indicate the reliability of those mean values. These tend not to satisfy any substantial objective. One feature that both these approaches have in common is that they are mostly used deterministically. A *deterministic* model implicitly assumes that its mathematical links between system mechanisms are sufficiently accurate to produce predictions without the need for any form of error bounds on them.

It is proposed here that the models used for predicting ill-defined system outputs

- be *specific* to the objectives that management requires; and
- possess a useful *statistical* or stochastic basis to account for uncertainty and, if possible, to allow levels of reliability to be attached to the estimated model parameters and hence the model predictions.

It is instructive to demonstrate how such model types are consistent with the risk assessment approach. Consider a hypothetical polluting human activity of fixed intensity. It is usually straightforward to calculate the source pollution from the technological system. From a statistically based model of the transport system, the probabilities of levels of dosages to receptor areas can be assigned. The result is a curve of the form stylised in Fig. 4. This procedure can be repeated for the full range of intensity of the human activity. The results can be summarised in a curve of the form in Fig. 5 where only two statistics for each of the curves belonging to the suite of curves of the type of Fig. 4 are displayed. They are the mean and standard error of Fig. 4 for each level of polluting activity. The standard error bounds are arbitrary but they usually will be larger (as portrayed) when models are applied to input data not generally encountered in practice ie very high source levels.

For the impact system, the dose-response curves obtained from modelling should also be probabilistic. Thus, a given dose has a certain response on average for a certain percentage of the population. Fig. 6 elucidates how the likely range of a dosage, got from Fig. 5, and Fig. 4 if more detail is required, yields the corresponding range of responses.

Major problems of performing a risk assessment

It is quite clear that there are many problems involved in the successful application of a comprehensive risk assessment procedure for proposed development. The two basic problems relate to the accuracy of both air quality modelling techniques and dose-damage information. Simpson and Hanna (1981) have concluded from extensive reviews that deterministic air quality models for inert gases are accurate to within a factor of two at best. Deterministic air quality models are the type most commonly applied and it is known that in general they are most accurate for average conditions, eg the Atmospheric Turbulence and Diffusion Laboratory (ATDL) model of Gifford and Hanna (1973) estimates annual means. However, it is obvious that the worst damages, at least in the short-term, are likely to occur under the higher ambient concentrations and often these result from abnormal atmospheric conditions such as the occurrence of very low windspeeds over significant periods of time. Therefore, deterministic air quality models of the type described are unlikely to be appropriate for damage evaluation from such events.

To compound these problems there is great disparity of agreement on dose-damage curves. For example, Morgan *et al* (1978) interviewed seven experts on the health effects of airborne sulphates inhaled by humans to elicit probability curves of the number of excess deaths per year for a steady state exposure of 20 micrograms per cubic metre ($\mu g/m^3$). The estimates were seen to vary widely with three distinctive distributional forms emerging, each with a different threshold value. Of course, the reasons for the uncertainty of damage functions relate to two sets of difficulties. One set is associated with abstracting the effects of correlated causal variables from epidemiological studies. The second set includes the difficulties of performing controlled experiments in the field or laboratory that are sufficiently comprehensive to be representative of practical situations. Such problems imply that it may be a long slow process towards obtaining a significant improvement in the current information base used for producing dose-damage relationships.

In response to the first problem concerning the relevance of solely deterministic air quality models for damage estimation, Daly and Jakeman (1984a, 1984b) provide a philosophy of modelling which can be used for risk assessment. It recognises the behavioural uncertainty of atmospheric transport systems and argues for the use of a probabilistic approach to take this into account. Jakeman and Simpson (1983) give examples of how the transport system can be modelled in practice: to provide outputs in a form relevant as dose input information for the calculation of damages; and to provide enhanced accuracy of such outputs. In particular, they show that maximum pollution concentrations can be modelled quite successfully. Simpson *et al* (1983) develop a hybrid deterministic/statistical model (see Appendix VII for the essential elements of such a model) which predicts maximum total suspended

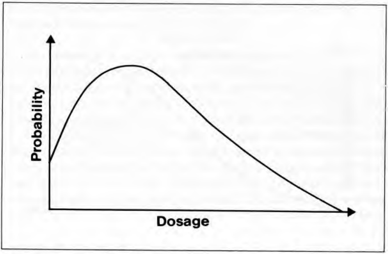


FIGURE 4 Schematic diagram showing likelihood of dosage to receptor areas for a fixed level of human activity

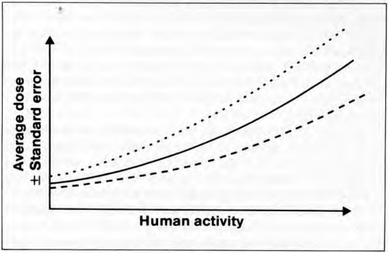


FIGURE 5 Schematic diagram showing mean and standard error only of dose from Fig. 4 as the level of human activity changes

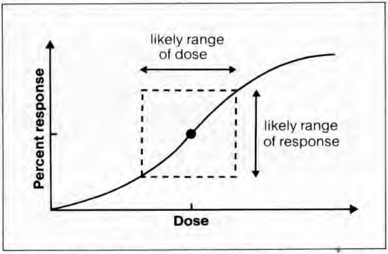


FIGURE 6 Schematic diagram showing the likely range of impacts as the bounds of dosage change

particulates (TSP) concentrations in Brisbane and carbon monoxide in Canberra, and Simpson and Jakeman (1984) have applied the model to ten years of daily acid gas recordings from Newcastle (see Chapter 5 for some of the results. It is based upon a relevant deterministic model used within its range of applicability to predict percentile values on a concentration curve of assumed parametric form. The values determine the parameters of the curve from which the maximum can be derived. The approach predicted maxima to within a factor of two accuracy. It now has been applied to low level area sources of the type above, to elevated point sources (Jakeman and Simpson 1985; Taylor *et al* 1985a) and to a line source (Taylor *et al* 1985b).

Jakeman *et al* (1985) have shown that a Gaussian plume model can be used with similar accuracy to predict the position and magnitude of sulphur dioxide maxima from an elevated point source (see Chapter 4 for some of the results). In addition, Jakeman *et al* (1984) have proposed a Monte Carlo simulation approach based on hybrid deterministic/statistical models to estimate median and maximum concentrations of carbon monoxide and nitrogen oxides due to emissions from a roadway line source. However the results have not been corroborated in the Hunter Valley as yet because of the unavailability of monitored ambient levels. The results of applying this speculative exercise to three major rural towns in the Upper Hunter Region are given in Chapter 7.

A simplified risk assessment procedure for the Hunter Region and other studies

It is evidenced from a perusal of quarterly reports of the NSW State Pollution Control Commission (eg 1982) that the general air quality of the Hunter Region has not deteriorated to levels experienced in other major industrialised countries. In Chapter 1 it is concluded that, aside from the localised high levels of lead particulates, which are experienced at Boolaroo to the south-west of Newcastle, there are no pollutants in the Hunter Region which at present regularly exceed environmental standards such as those adopted by the United States Environmental Protection Agency (USEPA). The two most significant air quality problems in the region appear to be acid gas levels in Newcastle City and dust pollution from open cut coal mines in the Upper Hunter Valley. However, average annual levels of acid gas in Newcastle hover below the US annual average sulphur dioxide standard of 75 $\mu g/m^3$ while the dust problem appears to be basically an aesthetic one.

Therefore, pollutants in the Hunter Region do not seem generally high enough yet to cause substantial damages to health, vegetation or materials, at least if possible synergistic effects of different pollutants are disregarded. This conclusion, in conjunction with the availability of modelling techniques which can predict maximum concentrations, suggests the basis of a risk assessment strategy which is of use for the planning of development and the management of that region's environment. That is, *when evaluating the impacts of current and proposed developments, a comparison can be made of maxima predicted under a range of meteorological conditions and development scenarios with levels which are known to cause minor damage.* Consequently, even a negligible risk strategy could be applied where development is preferred which keeps maxima in an area below thresholds for significant damage to receptors. At the very least, thresholds could be specified which allow for the identification of risk. It is worth emphasising that the term threshold is not employed here in its strictest sense. Thus, it is not used to denote a point below which it is assumed no damage occurs but as a general term denoting a point at which the damage to be indicated has been observed.

In Table 1 of Chapter 1, the pollutants of significance in the Hunter Region are noted and specific dose-damage information from the literature is provided for them in Appendix I. This is in the form of threshold levels at which either no damage or a specified damage has been observed. The thresholds are listed for human health, vegetation and materials and the relevant references to their original source are given. The guidelines used by the SPCC for individual pollutants are listed as well. Some attempt is also made to incorporate information on synergistic effects. It is anticipated that these data will prove a useful guide to workers involved in assessing environmental impacts in all locations. Throughout this monograph, the tables in Appendix I will be frequently referred to in order to assess the importance of predicted levels obtained from specific air quality modelling exercises.

As we progress through the individual chapters of Section II it will be seen that our approach to the assessment of regional air quality is less than traditional. We have not attempted to build regional scale deterministic models which in theory provide air pollution levels at all locations for given emission and meteorological conditions. This has been carried out, at least for sulphur dioxide and fluorides, elsewhere (eg James *et al* 1983; Bridgman *et al* 1983).

Our work complements these studies which in practice have provided relative indications of long-term pollution trends throughout the Hunter Region. This monograph concentrates on the 'hot spots' of pollution in the region and estimates air quality risks. This often entails calculation of the frequency of occurrence of short-term high pollution episodes. Where the data base allows, the monograph also indicates how these risks change with fluctuations in year-to-year meteorological regimes. The evaluation of high pollution episodes is facilitated by the use of statistical models. However, statistical models *per se* are non-predictive. The prediction of high pollution episodes, as Chapters 5 and 7 and to a lesser extent Chapter 4 show, requires appropriate augmentation of statistical models with deterministic models. A hybrid methodology incorporating the best features of deterministic and statistical models was specially developed in CRES during the course of this work to provide predictions of air pollution risks from given emission and meteorological conditions. More details of the CRES hybrid air quality models can be found in Jakeman *et al* (1984).

A comprehensive list of quite specific air quality studies carried out in the Hunter Region but not referred to in this monograph is Avery (1982, 1984), Hyde *et al* (1981), Carras and Williams (1984), Chambers and Bridgman (1984), Goldsworthy (1978), Guthrie and Lamb (1976), Lunnon (1984) and McRae *et al* (1954).

SECTION II

Specific air pollution problems

[illegible] and the relevant [illegible] are given. The good [illegible] pollutant [illegible] as well. Some attempt is [illegible] information on synergistic effects. It is [illegible] target [illegible]. Throughout [illegible] Appendix I [illegible] in order to [illegible] of predicted [illegible] statistical [illegible] modelling [illegible].

[illegible] through the following chapters of Section II it will be seen that [illegible] is [illegible] as [illegible] from [illegible] to [illegible] in all [illegible]. This has been [illegible] (e.g. [illegible] et al. 1988).

Our work [illegible] which at present [illegible] high pollution [illegible] in the [illegible]. The [illegible] on the 'hot spots' of pollution in the [illegible]. This often [illegible] of the [illegible] high pollution episodes. [illegible] The prediction of high pollution episodes is [illegible] by the use of statistical models. [illegible] The prediction of high pollution episodes, in Chapters 5 and 7 and [illegible] statistical models [illegible] statistical models [illegible] during the course of this work [illegible] and environmental conditions. More details of [illegible] can be found in [illegible] et al. (1988).

A [illegible] of air quality [illegible] in the [illegible] et al. (1983), [illegible] and [illegible] (1984), [illegible] and [illegible] (1986), and [illegible] (1988).

3

Air pollution from mining activities in the Upper Hunter Region

Introduction

The State Pollution Control Commission has expressed serious concern about the effects of individual open cut coal mines on local residents and the local environment of the Upper Hunter Region (NSW SPCC 1983). Given sufficient markets and adequate provision of infrastructure, coal mining activity will continue to expand in the region. An accurate forecast of the likely increases in coal production is of course difficult to guarantee. Suffice to say that it is possible for the current rate of production from open cut mines to double by the end of the decade and for the increase to continue to the year 2000. Fig. 7 shows the extent of existing and proposed open cut collieries in the Upper Hunter Region. The major effects of such mining come from dust and noise emissions due to mining operations and associated transport activities. Because of the special importance of dust pollution in the region the next section briefly describes its effects in more detail than is provided in Appendix I.

Effects of dust

Dust has the potential to cause damage to public health and welfare. The latter concept includes damage to vegetation, materials, visibility, climate and some aesthetic factors. In 1971, concern for health and other damage effects of particulates led the United States to promulgate Federal Standards for enforcement by the Environmental Protection Agency (USEPA).

These are summarised in Table 3 and take the form of a primary standard to protect public health and a secondary standard to protect public welfare. Both standards are for total suspended particulates (TSP) and do not take particle size into account below 45 microns (μm). The National Health and Medical Research Council (NHMRC) of Australia has also recommended a maximum permissible level for TSP. It is 90 μgm^{-3} for an annual geometric mean.

Damage to human health by dust is generally brought about by interaction with the three major regions of the respiratory tract. Of these, the principal problems arise from particles deposited in the tracheobronchial region, and the fine particles which may be absorbed in the alveolar region of the lung. Not surprisingly, increasing attention has been paid since 1971 to particle size, and particulates less than 15 μm have been identified as the inhalable variety which lead to health damages.

TABLE 3 USEPA air quality standards for particulates[(a)]

Primary[(b)]	75 μgm^{-3} annual average limit
Primary[(b)]	260 μgm^{-3} 24 hr limit
Secondary[(c)]	60 μgm^{-3} annual average limit
Secondary[(c)]	150 μgm^{-3} 24 hr limit

(a) defined as particles with size < 45 μm

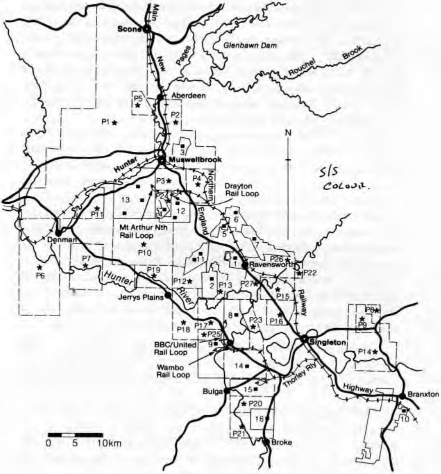
(b) standard to protect public health

(c) standard to protect public welfare

Source: US Federal Register, 1971.

This has prompted proposals for health standards incorporating particle size (Hileman 1981). In fact, recent proposals for a new primary standard for the United States, which applies to particles either less than 10 μm or less than 15 μm, have been placed before the US Clean Air Scientific Advisory Committee. These proposals have been critically reviewed by Hileman (1981) but have not yet been incorporated in legislation. To complicate matters further it is more likely that particles with diameters less than 1 μm are of most importance in pulmonary problems (Natusch and Wallace 1974).

Damage to vegetation arises from the accumulation of dust on plants. If the dust is not inert then a potential problem arises from the possible toxic effects of chemicals at the plant surface. Dust deposition can also lead to the formation of layers or crusts which physically hinder photo-



S/S
COLOUR.

FIGURE 7 The extent of existing and proposed open cut collieries in the Upper Hunter Region.

Source: NSW SPCC, 1983.

synthesis, slow carbon dioxide uptake and affect the rate of starch formation. In addition, the normal gas exchange between plant and atmosphere can be interrupted by the physical blocking of stomata. The toxicity and crusting problems are facilitated by moisture on the plant surface. In the first case, the moisture takes toxic chemicals into solution for uptake by the plant, and in the second it may hydrate certain dusts causing crusts. However, much of the available information on the effects of dust on plants is relevant to cement kiln dusts which contain calcium silicates that hydrate to form crusts on plant surfaces. Damages arising from the physical blocking of stomata are less quantified than for the chemical interactions, although such damage has been reported for broad leaved shade trees and conifers.

The USEPA has been reviewing national ambient air quality standards for particulates and believes that there is no need for a particulate standard designed solely to protect vegetation. The evidence is that for basically inert, insoluble dusts, observable injury to vegetation occurs only when deposition is extremely high.

Particulate damage to materials arises from abrasion when particles are impressed upon the materials, from the action taken to remove particles embedded on surfaces, and from chemicals within or absorbed by the dust which attack the material. The main effects are the corrosion of metals and the deterioration of building materials, particularly concrete and painted surfaces. It seems that the main issue to consider is the chemical nature of the dust and the availability of acid gases such as sulphur and nitrogen oxides to set up synergistic effects.

Deterioration of visibility either by a cumulative regional haze or from individual plumes is caused by the finer dust particles. This can be measured but the perception of the level of significance of the problem can vary.

This section has served to emphasise the uncertainties associated with the quantification of threshold levels for damage to vegetation and materials and for loss of amenity in general. It argues for a 'bottom-up' approach involving determination of the population of damage receptors around mining developments. This allows a definition of the classes of damage which merit the most serious attention.

Consider firstly the likely damages to vegetation. From this brief review it is possible to conclude that some damage could occur in very high dustfall areas. However, this is likely to be very close to mine pits where the damage should be minor compared to that caused by clearing sites for industrial operations. For material damages it is clear that there are few if any monuments and little substantial building in the areas of mining activity. The SPCC also regard it as unlikely that there will be a regional haze caused by mining since only a small proportion of the emitted particles are in the size range which affects visibility most (0.1 to 2 μm). However, it is well known that sometimes there are visible dust plumes hovering over individual mines.

This leaves the effects on health and loss of amenity for consideration. Suspended particulate data in the Ravensworth area collected by the Electricity Commission's hi-volume samplers indicate that both the USEPA primary standard for total suspended particulates and the NHMRC's maximum permissible level are likely to be exceeded on occasions for current production levels. While air quality standards are often conservative in nature, the levels do suggest that care should be taken if emissions were to significantly increase over those currently released. Because of the relationship of health effects to particle size (especially those below 10 μm) it is also important to obtain more information than is known on the size distribution of particles. Dichotomous samplers differentiating above and below 10 μm would be useful here. Checks need also be kept on the levels of sulphur oxides and nitrogen oxides in areas of high suspended particulate concentrations because of possible synergistic effects. This will be considered more fully in the next chapter.

While there is some uncertainty about the concentration of small size particulates and their health effects there is strong evidence that dust and noise from the open cut coal mining activity constitute nuisance problems in the Upper Hunter Region. In view of the importance of general loss of amenity as an aesthetic damage due to particulate pollution, an objective attitude/perception survey was carried out for selected population groups. Because of the special significance of this pollution problem, the survey details are provided later in a separate section.

Modelling particulate pollution

Ideally it would be useful to be able to predict accurately both the ambient concentrations of suspended particulates and the deposition of dust from all mining activities. Table 4 lists major emission sources and tentative emission factors estimated by the SPCC for major dust polluting activities associated with open cut coal mining in the Hunter Valley. Prediction of dust concentrations and dustfall from such factors and specific meteorological conditions aid assessment of impacts from new mines and mine extensions.

Unfortunately such mathematical modelling is fraught with major difficulties and uncertainties, even when compared with more traditional air pollution modelling. Butt *et al* (1982) have detailed these problems, referring to the difficulties in specifying the full probability distribution of emission factors for each activity, the microscale nature of the dispersion and hence the importance of both small changes in terrain and local meteorological effects. When modelling dust deposition there are additional problems to those of modelling dust concentrations. In the former case there must be assumed some manner of fallout with distance, wind speed and particle size, yet experimental techniques have to date failed to quantify such a relationship satisfactorily.

TABLE 4 Emission factors for Hunter Valley coal mines

Haul trucks: 4.0 kg per vehicle kilometre travelled	
Blasting of overburden and coal:	$\frac{758A^{0.8}}{M^{1.9}D^{1.8}}$ kg (A = area blasted in m^2 D = depth of blast in m M = % moisture content)
Loading by truck and shovel:	.01 kg/tonne of overburden .02 kg/tonne of coal
Drilling:	0.6 kg/hole
Truck dumping:	.02 kg/tonne of overburden .06 kg/tonne of coal
Exposed areas:	0.4 kg/hour/hectare
Topsoil removal:	14 kg per scraper hour
Dragline:	.02 kg/m^3

Source: NSW SPCC, 1983.

Nevertheless there has been and will continue to be a need to estimate the future impacts, and especially the 'hot spots', under likely development scenarios for open cut coal mining development in the Hunter Valley. The SPCC has therefore undertaken mathematical modelling in order to gauge at least the relative effects of development. Their results indicate that at a peak mining period in the valley, a deposition level of 4 g/m^2/month (annual average) could be exceeded in populated areas such as Ravensworth, Glennies Creek, Broke, Warkworth, Singleton and South of Muswellbrook (*see* Fig. 8). This is the level at which the SPCC believes a loss of amenity will first be perceived. They regard the deposition level of 10 g/m^2/month (annual average) as an unacceptable annual average. Support for the choice of these guidelines is provided by the survey results reported in the next section.

The environmental survey

Many of the adverse effects of open cut coal mining activity in the Upper Hunter Region are largely unquantifiable, for example dust and visible pollution. Effects of this type are largely of an aesthetic nature providing nuisance value to the population. Consequently the degree of the effect is dependent upon perceptions of it. Knowledge of the attitudes of the potentially affected population is useful in determining the significance of disamenity suffered. Furthermore, a survey was seen as a useful tool to provide some definition of pollution levels, especially with respect to dust, which cause increased annoyance over normal perceptions.

The survey obtained information on respondents' attitudes to a whole range of environmental problems. These were industrial smoke, street litter, trucks, industrial noise, dust, cigarette smoking, recreational area litter, odours, river pollution, lack of sewerage services, main road proximity. In this way the specific problems associated with mining activities were not unduly highlighted and a comparison could also be made between the perception of environmental problems associated with mining versus non-mining activities.

The populations surveyed were from the fringe open cut mining areas of Broke, Maison Dieu, Ravensworth, South Muswellbrook and Warkworth. A control population was also surveyed in Murrurundi since it is largely unaffected by the developments in question. A location map of these communities is shown in Fig. 8.

The survey consisted of 20 questions which were framed by a psychologist. It sought responses of two types with some questions open ended and others requiring categorisation. The survey form which is reproduced in Appendix III consisted of four basic sections:

- Demographic: questions 1 to 5 sought basic impersonal demographic data
- Quality of life: questions 6 to 10 sought information relevant to the quality of life experienced at the locations
- Quality of environment: questions 11 to 15 and question 20 sought information on what is perceived as an environmental problem and on its degree of severity in the immediate vicinity
- Health: questions 16 to 19 were framed to determine if any undue health problems occur in any of the localities.

Prior to the final survey a pilot survey was carried out in Cessnock to establish the utility and internal consistency of the questionnaire and to refine the wording of questions where deficiencies were revealed. In

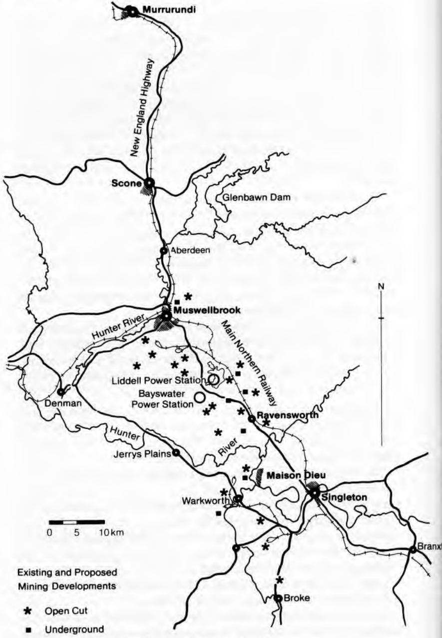


FIGURE 8 Map showing localities surveyed

general, the pilot survey indicated understanding and showed successful completion of answers.

The method of survey was as follows. Residents were sampled randomly from electoral rolls and forms were posted to them. Because of the small populations at Maison Dieu, Ravensworth and Warkworth everyone on the electoral roll in those locations was posted a form. Collection, however, was initially done by calling at each address to encourage completion of the questionnaire. Return addressed envelopes and, if necessary, new forms were left with those who had not completed the questionnaire. Overall the response rate was relatively low at 36 per cent and the sample sizes that resulted were relatively small at some locations. This required special attention in the analysis such as grouping of categories in order to allow a reasonable degree of statistical confidence. Response statistics for the surveyed populations are provided in Table 5.

Demographic results

Table 6 provides a summary of the demographic data. This shows that overall the male/female response was about even but in some locations female responses outnumbered males about two to one. The age distribution also varies with Warkworth providing the youngest respondents and Murrurundi the oldest.

The dominant occupation is home duties followed by semiskilled and unskilled. Maison Dieu has the greatest percentage of people involved in agriculture whereas Murrurundi has the greatest percentage of retired/pensioners. The respondents of the other four locations have a reasonably similar distribution of occupations.

Not surprisingly, employment-related reasons dominantly attracted people to their respective locations, particularly to Warkworth and South Muswellbrook. Most of the surveyed people who have moved into the locations come from elsewhere in New South Wales, a significant portion coming from elsewhere in the Hunter Valley and from smaller centres within the state.

Quality of life results

The data summaries pertaining to quality of life questions are summarised in Table 7. Respondents at Ravensworth, South Muswellbrook and Warkworth are least satisfied with their present place of residence as indicated by their desires to reside elsewhere. The respondents from Murrurundi appear to be quite happy with their location, some 50 per cent stating Murrurundi as the place they would like to live but this

TABLE 5 Response statistics for the surveyed locations

		Location			
Number of questionnaires	Row operation	Broke	Maison Dieu	Murrurundi	Ravensworth
Posted out	(A)	60	41	100	59
Hand delivered*	(B)	33	15	30	15
Returned to sender uncompleted	(C)	11	3	6	4
Effective delivery	(A+B–C)	82	56	124	70
Received completed	(D)	24	16	42	20
Received blank	(E)	4	3	1	1
Total received	(D+E)	28	19	43	21
Response$^+$ Rate (%)	$\frac{(D)}{(A+B-C)}$	29	30	34	29
Return^x Rate (%)	$\frac{(D+E)}{(A+B-C)}$	34	36	35	30

* Approximate only
\# Forwarded questionnaires
\+ Useful response rate
x Actual return rate

proportion is exceeded by Maison Dieu respondents, 60 per cent of whom consider their present place of residence as the desirable one. Overall 31 per cent of respondents residing in the mining areas indicated that their present location was their desirable place of residence. Environmental reasons dominated respondents' choice of a desirable location. Note that in this context 'environmental' includes such variables as climate, pollution, peace and quiet, seclusion, views and cleanliness.

The listing of the enjoyable things about living in their location revealed that in general the respondents thought the Hunter Valley had a good environment where the definition includes the concepts above. Practical reasons such as availability of employment, housing, provision of certain facilities etc. were rated highly for Warkworth, Ravensworth, Broke and South Muswellbrook with employment opportunity being the item of greatest significance.

Items which were disliked were primarily related to the availability or lack of practical things such as poor facilities, distance to facilities, inadequate water supply, shortage of housing, etc. Only Ravensworth did not rate highly for such practical reasons, the major discontent being the mining/developments in the area, rating some 52.3 per cent amongst

Location			
South Muswellbrook	Warkworth	Other#	Total
100	72	—	432
3	20	—	116
9	11	—	44
94	81	—	504
43	30	6	181
1	6	—	16
44	36	6	197
46	37	—	36
48	44	—	39

all responses. Overall 41 per cent of respondents in the mining areas indicated a dislike of some aspect of the mining developments. The responses from the town of Murrurundi, being far from mining developments, showed a low degree of concern with respect to the coal industry.

Items desired to be altered correlated well with disliked items. The localities of Maison Dieu, Ravensworth and Warkworth yielded responses showing a strong desire to alter facets of mining developments, these mainly being associated with the reduction/cessation of dust (especially at Ravensworth), noise and the numbers of coal trucks. Overall, 20 per cent of responses from the mining areas indicated a desire to change some aspect of mining developments. Once again, the responses to this item reflect that Maison Dieu and Ravensworth are the most adversely affected by mining. These are followed by Warkworth, with Murrurundi the least. Finally, it is interesting to note that the desire to alter things for practical reasons generally outweighed the desire for altering mining related problems. The exception, however, is Maison Dieu where 32 per cent of residents wished to alter mining related problems compared to 19 per cent for practical reasons.

Table 8 shows how respondents rated their present location with respect to their previous location. The rankings in the tables indicate that the populations of Ravensworth and Warkworth are the least happy with their locations, whilst those at Broke are generally happier than they were at their old location.

TABLE 6 Demographic data

	Location (%)*							
Demographic Variable	Maison Dieu		Warkworth		Ravensworth		Broke	
(Sample Size)		(16)		(30)		(20)		(24)
Sex								
Male		66.7		48.3		55.0		33.3
Female		33.3		51.7		45.0		66.7
Age								
16–35 years		53.3		60.7		52.6		65.2
36–55		40.0		35.7		31.6		17.4
56–		6.7		3.6		15.8		17.4
Occupation R = Respondent S = Spouse	R	S	R	S	R	S	R	S
Home duties	13.3	33.3	40.0	47.8	38.9	46.7	43.5	23.5
Prof/admin	.0	.0	16.6	8.6	16.7	6.7	17.4	17.6
Clerical	.0	.0	.0	4.3	.0	6.7	.0	5.9
Service/trades	6.7	8.3	3.3	.0	5.6	13.3	17.4	29.4
Self-employed	.0	.0	.0	.0	.0	.0	.0	5.9
Semi/unskilled	13.3	8.3	26.7	30.4	16.7	20.0	.0	11.8
Retired/pensioner	.0	.0	6.7	4.3	11.1	6.7	13.0	.0
Student	6.7	.0	3.3	.0	.0	.0	.0	.0
Primary producer	60.0	50.0	3.3	4.3	5.6	.0	4.3	5.8
Unemployed	.0	.0	.0	.0	5.6	.0	4.3	.0
Length of time in area								
0–2 years		6.7		26.7		36.8		16.7
3–5		26.7		46.7		15.8		16.7
6–10		13.4		3.3		5.9		20.8
11–20		20.0		13.3		15.8		16.7
21–		33.3		10.0		26.3		29.2
Why moved to area								
Not applicable		26.7		3.4		27.8		21.7
Employment related		33.3		62.1		27.8		43.5
Personal reasons		6.7		10.3		16.7		13.0
Other		33.3		24.2		27.7		21.8
Previous place of residence								
Not applicable		26.7		3.4		27.8		21.7
Hunter Valley		40.0		27.6		50.0		13.0
Major NSW City		.0		10.3		.0		17.4
Other NSW		26.7		48.3		22.2		30.4
Other		6.7		10.3		.0		17.4
Time at previous residence								
0–2 years		33.3		20.7		11.1		21.7
3–5		6.7		31.0		16.7		17.4
6–10		.0		17.2		22.2		8.7
11–20		13.4		13.8		5.6		17.4
21–		20.0		13.8		16.7		13.0
Not applicable		26.7		3.4		27.8		21.7

* Percentages shown are percentages of valid responses, ie response of 'no response' has been excluded.

Location (%)*					
Murrurundi		South Muswellbrook		Total	
	(42)		(43)		(175)
	37.2		57.1		48.0
	62.8		42.9		52.0
	28.6		47.1		47.3
	45.2		37.6		37.9
	26.2		14.7		14.8
R	S	R	S	R	S
30.2	30.3	16.7	40.6	29.8	36.8
1.6	9.1	28.6	12.5	17.0	9.8
4.7	6.1	9.5	3.1	3.5	4.5
11.7	6.1	16.6	21.9	11.1	12.8
11.6	6.1	.0	.0	2.9	2.3
4.7	15.1	16.7	15.6	12.9	17.3
16.3	18.2	11.9	6.3	11.1	7.5
4.7	.0	.0	.0	2.3	.0
4.7	9.1	.0	.0	8.2	8.3
.0	.0	.0	.0	1.2	.0
	11.6		7.5		16.0
	14.0		12.5		20.6
	11.6		25.0		13.7
	2.3		22.5		13.7
	60.5		32.5		33.7
	32.6		31.7		24.0
	30.2		48.8		40.6
	16.3		14.6		13.1
	20.9		4.9		22.3
	32.6		31.0		24.9
	7.0		14.3		20.7
	11.6		26.2		13.6
	30.2		16.7		29.0
	18.6		9.5		11.8
	14.3		7.3		15.4
	23.8		7.3		17.1
	4.8		9.8		9.7
	11.9		24.3		14.9
	9.5		19.5		14.3
	35.7		31.7		26.3

TABLE 7 Quality of life data

	Location* (%)			
Quality of life variable	Broke	Maison Dieu	Murrurundi	Ravensworth
(Sample Size)	(24)	(16)	(42)	(20)
Desirable place of residence				
Present place	43.5	60.0	55.0	11.1
Coastal regions	30.4	6.7	7.5	16.7
Elsewhere	26.1	33.3	37.5	72.2
Reason for place being desirable				
Satisfaction here	42.1	36.4	42.9	25.0
Practical	.0	27.3	7.1	12.5
Environmental	57.9	27.3	32.1	62.5
Personal	.0	9.1	17.9	.0
Enjoyable items				
(No. responses)#	(64)	(33)	(107)	(35)
Practical	28.1	9.1	13.1	28.6
Environmental	46.9	66.7	55.1	48.6
Personal	10.9	12.1	15.0	2.9
Other	14.1	12.1	16.8	20.0
Disliked items				
(No. responses)#	(63)	(40)	(104)	(44)
Practical	49.2	60.0	65.4	29.5
Mining development related	14.3	25.0	1.0	52.3
Other	36.5	15.0	33.7	18.2
Items to alter				
(No. responses)#	(55)	(31)	(85)	(35)
Practical	36.4	19.4	57.6	34.3
Mining development related	14.5	32.3	1.2	31.4
Other	49.1	48.4	41.2	34.3
Comparisons to last place of residence				
Rates lower	5.0	12.5	6.3	41.7
Neutral	15.0	25.0	21.9	33.3
Rates higher	80.0	62.5	71.9	25.0
Reasons for comparative judgement				
Practical	23.1	12.5	9.5	20.0
Environmental	15.4	25.0	9.5	20.0
Other	61.5	62.5	81.0	60.0

* Percentages shown are percentages of valid responses only.

\# Allowance for three responses per respondent.

Location* (%)		
South Muswellbrook	Warkworth	Total
(43)	(30)	(175)
25.0	25.9	36.8
30.0	44.4	23.3
45.0	29.6	39.9
20.0	5.9	29.3
12.0	29.4	12.9
56.0	52.9	48.3
12.0	11.8	9.5
(95)	(64)	(398)
30.5	32.8	23.9
32.6	45.3	47.2
14.7	9.4	12.1
22.1	12.5	16.8
(109)	(67)	(427)
42.2	53.7	51.1
13.8	16.4	16.2
44.0	29.9	32.8
(97)	(70)	(373)
39.2	32.9	39.7
11.3	25.7	15.8
49.5	41.4	44.5
21.9	29.6	18.3
18.8	29.6	22.9
59.4	40.7	58.8
15.4	26.7	17.3
23.1	20.0	17.3
61.5	53.3	65.3

TABLE 8 How respondents rated their existing location with their previous location

Location	% Respondents who have moved	Ranking Rates higher
Broke	78.3	1
Murrurundi	67.4	2
Maison Dieu	63.3	3
South Muswellbrook	69.0	4
Warkworth	96.6	5
Ravensworth	72.2	6

In summary, the following points emerge with respect to feelings on the 'quality of life' at the survey locations:

- Within the mining areas approximately 59 per cent of respondents expressed no feelings of discontent towards the mining industry. Additionally general environmental reasons rated the highest overall amongst enjoyable items listed.
- In general, Ravensworth appears to be the area with the greatest concern for impacts from the mining industry, followed by Maison Dieu and to a lesser extent Warkworth. However, Maison Dieu respondents feel most strongly about altering these but at the same time rate their existing location highly.
- A major concern of many people is the poor facilities served them. In fact the vast majority of people listed some practical need as the first item they would like to alter.
- Respondents from Murrurundi rarely mention mining developments in any answers to questions. This is not unexpected and is supportive of the fact that Murrurundi is a town largely unaffected by the developments, and in this sense is a suitable control population.

Quality of environment data

This section of Chapter 3 presents the body of information for which the survey was primarily designed: to gauge the relative effects of different potential and endured environmental impacts. This information basically consists of answers to the following questions:

- What environmental problems upset you?
- How frequently do you notice them?
- Do any of these problems directly affect you?

- If so, to what extent, do they merely constitute an aesthetic/nuisance problem or take the form of more serious effects?
- What action (if any) do you take to alleviate these problems?
- Do you feel something can be done about these?
- Whose responsibility do you feel it is to do this?

The spectrum of answers obtained will be elucidated in the forthcoming subsections.

Upsetting environmental problems and the degree to which they are observed (Questions 11, 12)

To enable easy comparisons of how the respondents at each of the six locations feel about eleven environmental factors (industrial smoke, litter on streets, trucks, industrial noise, dust, cigarette smoking, litter in recreational areas, odours, river pollution, lack of sewerage services, proximity to main roads) and how often they notice these environmental problems, two summary tables, namely Tables 9 and 10, have been prepared. Table 9 contains details of the 'annoys a lot' category for the degree of upset (survey question 11) and Table 10 contains details of the 'noticed frequently' category for the degree of noticing these factors (survey question 12).

Within these tables the ranking is done on the basis of the percentage of responses for each class. The class with the highest response rate receives the highest ranking.

Table 11 contains a list of what environmental problems are most upsetting and most noticed by the respondents of each location. As can be seen by examination of this table there is a high degree of correlation between what upsets people and how frequently they notice it. This is not surprising as peoples' feelings are generally dictated by perceptions. Thus, if a problem is out of an individual's sphere of experience, it would not be expected that he/she would possess strong attitudes towards it. This is corroborated by Table 12 and Fig. 9 which show the overall picture of degree of upset and the degree of notice. The dashed line in Fig. 9 is the line upon which all points might reasonably be expected to lie based on the above perception-produces-attitudes reasoning.

Table 13 places the relation between the degree of notice and degree of upset on a more formal basis using a chi-square test and Cramer's V statistic. Here the large values of χ^2 and V indicate the existence of a systematic and strong relationship between attitudes and perception. For each of the eleven environmental problems the value of χ^2 obtained has less than 0.05 per cent chance of being spurious; that is, the

TABLE 9 Environmental problems which 'annoy a lot'

Environmental problem	Location							
	Broke		Maison Dieu		Murrurundi		Ravensworth	
	%	Rank	%	Rank	%	Rank	%	Rank
Industrial smoke	45.0	6	75.0	7	29.6	9	33.3	7
Street litter	72.7	2	80.0	6	74.3	1	52.9	5
Trucks	56.5	3	83.3	3	41.7	7	66.7	3
Industrial noise	42.9	7	100.0	1	28.6	10	31.3	9
Dust	45.5	5	93.8	2	48.6	4	80.0	1
Cigarette smoking	31.8	9	81.8	5	44.1	5	35.3	8
Recreational area litter	86.4	1	60.0	10	74.3	1	66.7	3
Odours	31.6	10	70.0	8	42.3	6	50.0	6
River pollution	50.0	4	83.3	3	67.7	3	76.5	2
Lack of sewerage services	33.3	8	33.3	11	40.7	8	31.3	9
Main road proximity	9.5	11	62.5	9	20.6	11	30.0	11

TABLE 10 Environmental problems which are 'noticed frequently'

Environmental problem	Location							
	Broke		Maison Dieu		Murrurundi		Ravensworth	
	%	Rank	%	Rank	%	Rank	%	Rank
Industrial smoke	38.1	8	66.7	8	23.1	9	35.3	9
Street litter	80.0	2	77.8	4	82.9	1	70.6	2
Trucks	65.2	3	90.9	2	44.7	6	72.2	1
Industrial noise	42.9	6	83.3	3	25.9	8	44.4	6
Dust	50.0	4	92.3	1	57.6	3	66.7	4
Cigarette smoking	40.0	7	60.0	9	45.5	5	35.3	8
Recreational area litter	85.7	1	77.8	4	71.4	2	70.6	2
Odours	33.3	10	70.0	7	20.0	11	33.3	9
River pollution	47.6	5	72.7	6	53.3	4	58.8	5
Lack of sewerage services	36.4	9	50.0	10	29.2	7	35.7	7
Main road proximity	19.0	11	33.3	11	21.9	10	26.3	11

Location					
South Muswellbrook		Warkworth		Total	
%	Rank	%	Rank	%	Rank
44.7	6	36.0	10	40.4	9
71.8	2	66.7	3	70.0	2
66.7	3	36.0	10	55.8	5
34.2	9	48.1	7	41.8	8
63.2	5	46.2	8	59.7	4
35.9	8	50.0	6	43.0	7
87.5	1	80.0	2	78.7	1
43.2	7	65.4	4	48.5	6
64.1	4	80.8	1	69.0	3
30.6	10	53.8	5	37.8	10
16.7	11	40.0	9	25.0	11

Location					
South Muswellbrook		Warkworth		Total	
%	Rank	%	Rank	%	Rank
34.2	7	40.7	11	36.2	8
67.5	3	70.4	1	74.3	1
81.0	1	69.2	3	67.7	3
30.8	8	50.0	9	41.3	7
47.5	4	53.6	6	57.1	4
45.0	5	53.6	6	45.9	6
69.0	2	70.4	1	72.8	2
27.0	9	44.4	10	34.1	9
41.0	6	64.0	4	53.1	5
8.6	11	52.0	8	31.3	10
26.5	10	53.8	5	29.8	11

TABLE 11 First five problems by ranking at each of the six locations by degree of upset and degree of notice

	Ranking* by 'annoys a lot'		
Degree of upset Location	1	2	3
Broke	rec. litter	street litter	trucks
Maison Dieu	noise	dust	(trucks (river pollution
Murrurundi	(street litter (rec. litter		river pollution
Ravensworth	dust	river pollution	(rec. litter (trucks
South Muswellbrook	rec. litter	street litter	trucks
Warkworth	river pollution	rec. litter	street litter
Overall	rec. litter	street litter	river pollution

	Ranking* by 'notice frequently'		
Degree of notice Location	1	2	3
Broke	rec. litter	street litter	trucks
Maison Dieu	dust	trucks	noise
Murrurundi	street litter	rec. litter	dust
Ravensworth	trucks	(street litter (rec. litter	
South Muswellbrook	(trucks	rec. litter	street litter
Warkworth	(street litter rec. litter		trucks
Overall	street litter	rec. litter	trucks

* If problems were ranked equally the next rank position(s) is (are) left vacant.

probability of an incorrect conclusion being drawn is very low. This relationship between attitudes and perception is very important with respect to later analysis.

Elsewhere (Butt *et al*, 1983) the attitudes and perceptions of respondents have been analysed on the basis of sex, age, occupation and type of location. However, the results are of minor relevance and will be reported in the end-of-section summary.

Directly-affecting environmental problems (Question 13)

Question 13 sought to find out which (if any) of the previously mentioned eleven environmental factors directly affect the respondents. For

Ranking* by 'annoys a lot'	
4	5
iver pollution	dust smoking
ust	smoking
	street litter
iver pollution dours	dust lack of sewerage
ust	trucks
anking* by 'notice frequently'	
4	5
ust treet litter ec. litter	river pollution
iver pollution ust	smoking river pollution
ust iver pollution	smoking main road proximity
ust	river pollution

those problems named the mechanisms of effect were sought together with the form of remedial action taken.

Table 14 summarises the responses for 'directly-affecting items'. The response rates alone yield valuable information. The population of Maison Dieu are the most concerned as indicated by 75 per cent of the respondents having an average of 2.6 complaints each. Compared to the control region of Murrurundi, where 48 per cent of the respondents have an average of 1.6 complaints each, the level of complaints by Maison Dieu residents is high. The response statistics for the other four locations are all reasonably similar. In terms of the experienced problems

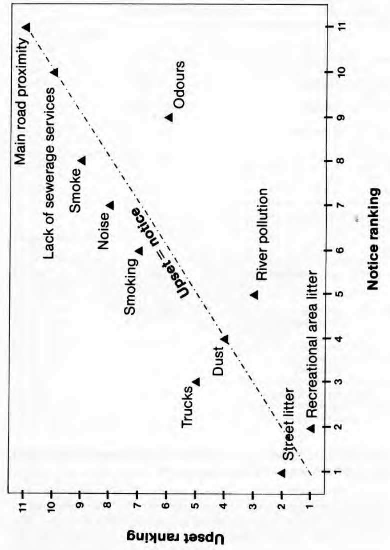


FIGURE 9 The degree of upset ('annoys a lot') versus the degree of notice ('notices frequently') for eleven environmental problems

TABLE 12 The ranking of the top categories of the 'degree of upset' and the 'degree of notice' possessed by these eleven environmental problems

Ranking	Environmental problem 'annoys a lot'	Environmental problem 'notices frequently'
1	recreational area litter	street litter
2	street litter	recreational area litter
3	river pollution	trucks
4	dust	dust
5	trucks	river pollution
6	odours	cigarette smoking
7	cigarette smoking	industrial noise
8	industrial noise	industrial smoke
9	industrial smoke	odours
10	lack of sewerage services	lack of sewerage services
11	main road proximity	main road proximity

TABLE 13 Statistical relations between the degree of upset and the degree of notice for the eleven environmental problems

	(upset-notice)*	
Environmental problem	χ^2	V#
Industrial smoke	72.6	0.53
Street litter	39.8	0.37
Trucks	81.2	0.50
Industrial noise	76.4	0.53
Dust	73.2	0.49
Cigarette smoking	111.3	0.62
Recreational area litter	58.1	0.44
Odours	56.2	0.46
River pollution	61.1	0.46
Lack of sewerage services	57.4	0.48
Main road proximity	100.0	0.60

* 3 classes of 'upset', and 3 classes of 'notice' giving 4 degrees of freedom. In all cases the significance of this value of χ^2 was < 0.0005.

\# V is Cramer's V statistic indicating the strength of the relationship on a 0–1 scale.

TABLE 14 Directly-affecting environmental problems

	Location							
Response statistics	Broke		Maison Dieu		Murrurundi		Ravensworth	
No. of responses*		37		31		32		34
Mean No. of responses# per respondent		2.2		2.6		1.6		2.4
Response rate for question+		71%		75%		48%		70%
Response Breakdown	%	Rank	%	Rank	%	Rank	%	Rank
Industrial smoke	.0	10	.0	8	.0	7	2.9	9
Street litter	13.5	3	3.2	7	15.6	3	2.9	9
Trucks	18.9	1	9.7	4	34.4	1	11.8	3
Industrial noise	16.2	2	22.6	2	.0	7	14.7	2
Dust	13.5	3	38.7	1	25.0	2	29.4	1
Cigarette smoking	8.1	6	6.5	5	12.5	4	5.9	6
Recreational area litter	10.8	5	.0	8	6.3	5	.0	11
Odours	2.7	9	6.5	5	.0	7	11.8	3
River pollution	.0	11	12.9	3	.0	7	8.8	5
Lack of sewerage services	8.1	6	.0	8	.0	7	5.9	6
Main road proximity	8.1	6	.0	8	6.3	5	5.9	6

* Up to four responses were allowed for each respondent. The percentages shown are in terms of responses received.

\# Based on the total number of respondents answering question 13 at each location.

\+ Based on the number of respondents.

Table 15 allows a more convenient appraisal of the most severe problems. Note that this table should be compared with Table 11. Table 11 indicates the problems which 'annoys a lot' and are 'noticed frequently' by respondents, whereas Table 15 indicates the problems directly affecting them. The main differences between these are that, in Table 15, trucks, dust and to a lesser extent noise have displaced litter as the highest ranked problems. Between the different localities in Table 15 the main differences can be summarised as

- Maison Dieu (which is on a no-through road) has the least problem with trucks
- the non-mining area (Murrurundi) has no noise problem, as is the case for the old mining area of South Muswellbrook. Noise is most

Location					
South Muswellbrook		Warkworth		Total	
53		43		230	
2.0		2.4		2.1	
70%		60%		63%	
%	Rank	%	Rank	%	Rank
7.5	5	.0	10	2.2	11
11.3	4	14.0	2	10.4	4
28.3	1	23.3	1	21.7	1
3.8	8	9.3	5	10.4	4
15.1	2	9.3	5	20.4	2
15.1	2	14.0	2	10.9	3
7.5	5	4.7	8	5.2	8
1.9	10	.0	10	3.5	9
3.8	8	11.6	4	6.1	6
.0	11	4.7	8	3.0	10
5.7	7	9.3	5	6.1	6

significant in the open cut mining areas of Broke, Maison Dieu and Ravensworth

- litter problems tend to be experienced more in the larger centres of Broke, Murrurundi and South Muswellbrook as well as in Warkworth
- the most significant problems generally experienced are trucks on roads and dust. Interestingly enough this seems to be the case irrespective of the proximity to mining activity. However, Ravensworth and Maison Dieu rate dust and noise well above the other directly affecting environmental problems.

Table 16 summarises the mechanisms of effect for these directly affecting environmental problems. By far the greatest effect is that of nuisance value. The respondents of Maison Dieu and Ravensworth feel

TABLE 15 First five (by ranking) most-experienced problems at each of the si locations

	Ranking*				
Location	1	2	3	4	5
Broke	trucks	noise	(street litter (dust		rec. area litter
Maison Dieu	dust	noise	river pollution	trucks	smoking odours
Murrurundi	trucks	dust	street litter	smoking	(rec. area litter (main road proximity
Ravensworth	dust	noise	(trucks (odours		river pollution
South Muswellbrook	trucks	(dust (smoking		street litter	(industrial smoke (rec. area litter
Warkworth	trucks	(street litter (smoking		river pollution	(noise (dust (main road proximity
Overall	trucks	dust	street litter	(street litter (noise	

* If problems were ranked equally the next rank position(s) is (are) left vacant.

TABLE 16 Mechanisms of effects of the directly-affecting problems in Table 14

	Location# (%)			
Mechanisms*	Broke	Maison Dieu	Murrurundi	Ravensworth
annoyance/inconvenience/ nuisance	60.0	39.3	61.5	37.5
hardship	20.0	39.3	11.5	28.1
onset of illness	3.3	7.1	11.5	9.4
hazard	10.0	3.6	15.3	9.4
other	6.7	10.7	.0	15.6

* Up to four responses were allowed for.

\# Based on responses received.

that personal hardship (for example, extra cleaning due to dust soiling) is a notable effect. Respondents from South Muswellbrook feel most strongly that a hazard (usually from trucks) is the effect.

A significant proportion of responses (30.6 per cent overall) indicate that people who feel they have been directly affected by an environmental problem take no positive action (see Table 17) to avoid or alleviate recurrence. In addition, Table 17 shows that 13 per cent of overall responses indicate cleaning is performed as a compensatory measure. Prevention seems to be adopted as an alternative to a solution in many cases. The preventative actions, consisting of using backroads to avoid trucks, shutting up the house to avoid dust input, using a clothes dryer in preference to outside line, etc. were commonly employed. Approximately 16 per cent of respondents complain to authorities and others responsible about their problems. The population of Maison Dieu appears to provide the most complaints followed by Ravensworth and Warkworth. Generally complaints seem to be higher in the mining areas (Broke is an exception) than in Murrurundi. It is interesting to note that overall only 15.5 per cent of people who feel they have been affected actually complain and try to solve the problems. The vast majority of the population takes little complaint action, even though extra hardship may be incurred or a nuisance effect experienced. This fact that complaints do not reflect the levels of community annoyance has been found in other surveys of attitudes to environmental problems (Ramsay 1978, Basarin and Cook 1982).

Location# (%)		
South Muswellbrook	Warkworth	Total
42.0	42.1	45.9
16.0	13.2	20.5
14.0	2.6	8.3
24.0	13.2	13.7
4.0	28.9	11.7

TABLE 17 Action taken against the directly-affecting environmental problems of Table 12

	Location# (%)			
Action taken*	Broke	Maison Dieu	Murrurundi	Ravensworth
Devices used	.0	6.7	.0	3.8
Nothing	46.7	20.0	32.0	30.8
Preventative	3.3	23.3	16.0	19.2
Complain	3.3	36.7	8.0	23.1
Move away	.0	.0	.0	.0
Cleaning	16.7	.0	32.0	11.5
Other	30.0	13.3	12.0	11.5

* Up to four responses were allowed for.

\# Based on responses received.

TABLE 18 The possibility of solving existing environmental problems

	Location (%)			
Solution possible#	Broke	Maison Dieu	Murrurundi	Ravensworth
(No. responses)	(18)	(13)	(25)	(16)
Yes	83.3	76.9	84.0	81.3
No	5.6	23.1	8.0	18.8
Some problems yes, some no	5.6	.0	4.0	.0
Undecided	5.6	.0	4.0	.0
How Solution could be Effected*				
Government/authority	33.3	25.0	14.3	37.5
Community	16.7	75.0	14.3	.0
Miscellaneous	50.0	.0	71.4	62.5

\# Based on responses received.

* Note this information was volunteered by respondents and represents the opinions of a low number.

Solution of environmental problems (Question 14)

Table 18 shows that 81.1 per cent of respondents overall believe something can be done to solve existing environmental problems. Respondents from Maison Dieu, Ravensworth and South Muswellbrook recorded the largest negative response. Some respondents also offered

Location# (%)		
South Muswellbrook	Warkworth	Total
.0	2.5	1.6
30.2	25.0	30.6
39.5	5.0	18.7
4.7	20.0	15.5
.0	10.0	2.1
11.6	10.0	13.0
14.0	22.5	18.7

Location (%)		
South Muswellbrook	Warkworth	Total
(31)	(19)	(122)
77.0	84.2	81.1
23.0	5.3	13.9
.0	5.3	2.5
.0	5.3	2.5
.0	27.3	20.4
.0	18.2	14.8
100.0	54.5	64.8

mechanisms by which solutions could be effected. These are shown in the lower portion of Table 18. Note that the miscellaneous category includes items such as 'use rail instead of roads for coal transport', or 'if people cared'.

TABLE 19 Delegation of responsibility to solve existing environmental problems

	Location (%)			
Responsible body*	Broke	Maison Dieu	Murrurundi	Ravensworth
(No. Responses)	(18)	(13)	(21)	(13)
Government/authority	55.6	46.2	66.7	84.6
Causee+	16.7	.0	4.8	7.7
Mining industry	16.7	30.8	.0	.0
Other	11.1	23.1	28.6	7.7

* Based on responses received.

+ Other than mining industry.

TABLE 20 Devices used to counter environmental problems

	Location (%)			
	Broke	Maison Dieu	Murrurundi	Ravensworth
(No. responses)	(13)	(15)	(25)	(14)
None	84.6	13.3	76.0	14.3
Single	15.4	26.7	24.0	42.9
Multiple	.0	60.0	.0	42.9

Responsibility to take action (Question 15)

Table 19 summarises the responses for this question. In general respondents feel that the government (federal/state/local) together with 'watchdog' agencies (State Pollution Control Commission, Department of Health etc.) are responsible for effecting some control/abatement of environmental problems. It is instructive to note that generally people feel a 'watchdog' approach is required. Another feature emerging from Table 19 is that in the case of Maison Dieu, respondents feel the mining industry has a large responsibility to effect a solution to 'existing problems', whereas for other places less responsibility is delegated to them. In the case of Ravensworth it can be said that this responsibility is largely unexpected since the experienced problems are predominantly mining produced.

ocation (%)		
South Muswellbrook	Warkworth	Total
(29)	(21)	(115)
86.2	66.7	69.6
6.9	4.8	9.6
.0	19.0	6.9
6.9	9.5	13.9

ocation (%)		
South Muswellbrook	Warkworth	Total
(33)	(17)	(117)
78.8	82.4	63.2
21.2	11.8	23.1
.0	5.9	13.7

Devices to counter environmental problems (Question 20)

The devices claimed to be installed for countering environmental problems are shown in Table 20. Such devices consisted of items such as air conditioners, water filters and clothes dryers. In many cases those respondents with an air conditioner would have been referring to 'heat' as the environmental problem rather than one of the eleven previously mentioned possibilities. Respondents with multiple devices would most likely be those with some existing problem (for example dust). Taking note of the previous comment in relation to air conditioners it is apparent that at both Maison Dieu and Ravensworth and to a lesser extent Warkworth there are existing environmental problems that are deemed necessary to counter. With regard to the types of devices, it seems highly likely that the problem these devices are intended to counter are excessive dust fallout. Note that the houses in Ravensworth hamlet were supplied (by the Electricity Commission at one stage) with devices to compensate for the loss of amenity imposed by dust from the nearby open cut coal mine.

Overview of quality of environment data

The questions outlined at the commencement of this section have basically been answered. In summary, there is a strong correlation between the degree to which an environmental problem upsets a person and the degree to which it is noticed. There appears to be a dependence upon age, sex, occupation and location for attitudes to environmental problems. In general, females appear to be more tolerant towards problems other than litter; and old people are more tolerant to items other than noise, trucks and smoking. People in mining areas notice noise, trucks and smoke more than those in non-mining areas. Vocation dependent differences are also evident. For example people involved with home duties are most sensitive to litter, otherwise people involved in the mining industry notice environmental problems more. Whether or not this is related to the greater occurrence of these is open to conjecture but such an hypothesis seems plausible when due consideration to the relation between the degree of upset and notice is given.

The types of environmental problems of greatest concern to the communities at each location can be connected to the population by consideration of the demographic data and the age, sex, occupation and location dependent associations given. These environmental problems generally produce an effect through annoyance or nuisance value. The degree of action devoted to resolving these difficulties is much lower than the severity of the problem as indicated by the totally open-ended question 13. Respondents feel that most of these problems can be solved, or at least alleviated, and tend to hold the Government or its agencies responsible for achieving better environmental quality.

The residents of Maison Dieu and Ravensworth perceive environmental problems associated with the mining industry such as dust, noise and trucks with a high degree of importance whereas general societal problems, such as smoking and litter are less dependent on location. The residents of Maison Dieu and Ravensworth also perceive the mining industry associated problems as more important than the general ones as listed in Table 11, whereas the former are well down in importance after the latter for other locations.

Health background data

Basic background health data consisting of the frequency of family members visits to doctors, common illnesses and any long term pre-existing illnesses were sought in order to ascertain if there were any excessive health effects associated with living in a region subject to coal based developments. Pollutants of potential concern in the region are dust and noise from the mining areas and sulphur dioxide, nitrogen oxides and particulates from power stations (see Chapter 1).

The health background information yields little information of significance. There seems to be little difference between mining and non-mining regions. Information on long term illnesses leads to similar conclusions. There is no significant difference in occurrence of bronchial problems or asthma in regions of high as opposed to low dustfall. Most long term illnesses are suffered by adults, the affliction being of a bronchial or aching type. The proportion of the populations who smoke is reasonably constant and so any possible variation in bronchial problems would not seem to be attributable to this cause.

Dust, noise and trucks—three environmental problems in detail

Three environmental problems, namely dust, noise and trucks, are to a large degree attributable to current coal mining and coal utilisation in the Upper Hunter Region. Other environmental problems, for example litter and cigarette smoking, are societal in nature, that is they exist in society independently of a mining industry and so will not be looked at here. In order to ascertain whether or not there are significant differences between the responses from different types of areas, the environmental problems of dust, noise and trucks will be looked at in detail. Table 21 indicates the types of sources responsible for each of these factors within the Upper Hunter Region. Note that in areas far removed from coal based developments the sources in the first two columns will not exist.

An increase of the sample size allows far more reliable statistical differences to be obtained. This can be achieved by grouping various locations together for different purposes. The different groupings used in the analysis here and the justifications for such groupings are presented in Table 22.

Dust

With the locations grouped according to Table 22 the attitudes of respondents to dust are presented in Table 23. Two null hypotheses were framed: the first H1 that dustfall is not more upsetting in regions of greatest levels; and the second H2 that dustfall is not more noticed in regions of greatest levels. It can be seen that the null hypothesis H1 can be rejected at the 1 per cent significance level and H2 cannot be rejected at the 5 per cent level, though hypothesis H2 can be accepted at the 10 per cent level of significance. The conclusion here is that dustfall is more upsetting in regions of higher dust fallout.

With respect to dustfall levels it is felt by the SPCC (Ferrari and Ross 1983) that an annual average dust fallout of 4 g/m^2/month in regions surrounding mining activity is the threshold for perception of loss of amenity. From experience this is the level at which members of the public are likely to complain. An annual average level of 10 g/m^2/month is felt to be totally unacceptable. In view of our findings and those of similar attitude surveys (Basarin and Cook 1982; Ramsay 1978) that the level of complaints is disproportionately low with respect to the degree of the problem experienced, it is conceivable that the threshold of perception of amenity loss occurs at an even lower level.

Figs. 10 and 11 summarise the attitudes towards and perception of dust for respondents together with the levels of dustfall experienced. These dustfall data from each set of monitors are detailed in Appendix IV and it is felt that they are quite representative of levels experienced at the time of the survey. Both Maison Dieu and Ravensworth experience

TABLE 21 Sources of dust, noise and trucks in the Upper Hunter Valley

	Source		
	Coal mining activities	Coal utilisation activities	General human activities
Dust	blasting, draglines, truck & shovel operations, haul roads, drilling, stockpiles, coal treatment facilities, exposed areas, haulage	power station emissions, conveyers, haulage	agriculture, activities in general (cities), unsealed roads
Noise	blasting, heavy machinery, trucks, sirens, conveyers	conveyers (and associated sirens)	traffic, factories, populations, trains
Trucks	mine pit operations, haulage on roads to rail heads or other users	road haulage to power stations	goods transport, services

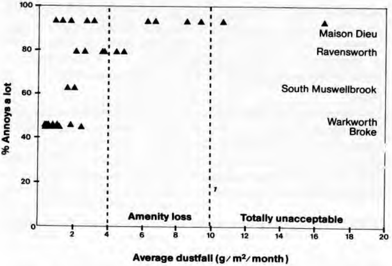


FIGURE 10 Attitudes towards dust versus the levels of dustfall (denoted by star) experienced (calculation of the levels is fully detailed in Appendix 4)

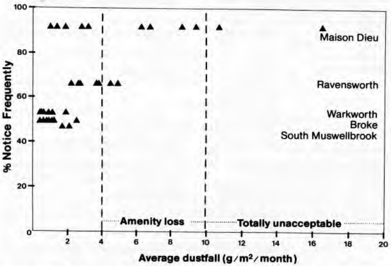


FIGURE 11 Perception of dust versus levels of dustfall experienced

sufficiently high levels to cause some loss of amenity, this being indicated by the increased degree of upset and notice afforded by dust at these locations. As a guide, it can be seen that approximately 40 to 50 per cent of respondents have strong feelings towards or a frequent degree of notice of dust as the grey area of amenity loss is approached.

Noise

Unfortunately a data base of noise levels for the various locations does not exist, and hence it is only possible to present a less complete approach than that used for the assessment of dust. Within the mining area there are two significant types of noise sources, these being either mine related, for example general pit operations, or transport related, for example trucks and conveyors. It is difficult to try to designate the

TABLE 22 Location groupings for various environmental problems and the rationale for such groupings

Environmental problem	Total sample size	Locations grouped	Reasons for groupings used
Dust*	97	Broke South Muswellbrook Warkworth	Medium dustfall levels, mining region.
	36	Maison Dieu Ravensworth	High dustfall levels, mining region.
	42	Murrurundi	Background dustfall levels, non-mining region.
Noise	133	Broke Maison Dieu Ravensworth South Muswellbrook Warkworth	Mining region.
	42	Murrurundi	Background noise levels, non-mining region.
Trucks	133	Broke Maison Dieu Ravensworth South Muswellbrook Warkworth	Mining region. Coal trucks add to truck traffic.
	42	Murrurundi	Non-mining region. Background truck traffic.

* See Appendix IV for representative dustfall levels.

TABLE 23 Contingency tables for attitudes and perception for the environmental problem of dust

	Location (%)			
Degree of annoyance	Maison Dieu Ravensworth	Broke South Muswellbrook Warkworth	Murrurundi	Total
(No. responses)	(36)	(86)	(37)	(159)
Annoys a lot	86.1	53.5	48.6	59.7
Annoys a little	13.9	31.4	35.1	28.3
No feelings	.0	15.1	16.2	11.9

$\chi^2 = 14.65$

Significance = 0.005 (4 degrees of freedom)

Cramers V = 0.215

Logical null hypothesis

H1 : Dustfall is not more upsetting in regions of greatest levels.

	Location (%)			
Degree of notice	Maison Dieu Ravensworth	Broke South Muswellbrook Warkworth	Murrurindi	Total
(No. responses)	(31)	(90)	(33)	(154)
Frequently	77.4	50.0	57.6	57.1
Occasionally	19.4	34.4	24.2	29.2
Rarely	3.2	15.6	18.2	13.6

$\chi^2 = 8.39$

Significance = 0.078 (4 degrees of freedom)

Cramers V = 0.216

Logical null hypothesis

H2 : Dustfall is not more noticed in regions of greatest levels.

locations surveyed as either mining noise affected or truck noise affected, hence the environmental problem of noise will be looked at solely in the comparative sense of, 'Is noise more of a problem in a mining area than a non-mining area?' In this comparison it should be noted that the control population (Murrurundi) is significantly the population with the greatest average age. For this reason, when the findings of a previous section are noted, namely old people are most affected by noise, the differences between mining and non-mining areas will be expected to be less than would be the case for an ideal control group.

Table 24 contains the results for this analysis which uses two null hypotheses H3 and H4. The hypothesis H3 is that noise is not more upsetting in mining regions while H4 is that noise is not more noticed in mining regions. It can be seen that we cannot reject the null hypothesis H3 at the 10 per cent level, whereas at the 5 per cent significance level we can reject the hypothesis H4. Thus at the 5 per cent level of significance noise is noticed more in mining regions than it is in non-mining regions. There does not appear to be any difference in attitudes towards noise between regions, though this finding could be related to the control group which as mentioned above is non-ideal in this case.

Trucks

A data set of traffic volumes as presented in Butt *et al* (1983), does exist for some of the locations surveyed, so some quantitative analysis is possible. As a first step we considered whether trucks are noticed more in mining regions than non-mining regions. Table 25 presents the results for this analysis which also uses two null hypotheses: H5 that trucks are not more upsetting in mining regions; and H6 that trucks are not more noticed in mining regions. The null hypothesis H5 cannot be rejected at the 10 per cent significance level. Thus it appears that there are no substantial differences of opinion with respect to trucks. However, null hypothesis H6 can be rejected at the 1 per cent level, that is respondents in mining areas do significantly notice trucks more often than those in non-mining regions. Consideration of the number of trucks used solely to haul coal on public roads would have led to this obvious statement.

Within the mining region itself there is a wide variation in heavy vehicle traffic volumes. Warkworth, Ravensworth and South Muswellbrook are subject to greater volumes than places such as Broke and Maison Dieu, itself on a no-through road. For residents in these locations it is instructive to check for differences in attitudes and try to relate these differences to the volumes of trucks encountered. Table 26 presents the results from a comparison of attitudes between regions of high and low truck densities. Neither null hypothesis H7, that trucks are not more upsetting in regions of greatest truck densities, nor H8, that trucks are not more noticed in regions of greatest truck densities, can be rejected at the 10 per cent level. Thus there are apparently no differences in attitudes towards trucks within a mining region. A possible explanation for this finding is that present lifestyles involve the use of motor vehicles almost daily with excursions away from the home being common, so that contact with trucks would still be significant despite low levels of contact in the vicinity of the home.

TABLE 24 Contingency tables for attitudes and perception for the environmental problem of noise

Degree of upset	Location (%) Broke Maison Dieu Ravensworth South Muswellbrook Warkworth	Murrurundi	Total
(No. responses)	(123)	(28)	(151)
Annoys a lot	62.6	48.6	59.7
Annoys a little	26.0	35.1	28.3
No feelings	11.4	16.2	11.9

$\chi^2 = 3.36$

Significance = 0.186 (2 degrees of freedom)

Cramers V = 0.15

Logical null hypothesis

H3 : Noise is not more upsetting in mining regions.

Degree of notice	Location (%) Broke Maison Dieu Ravensworth South Muswellbrook Warkworth	Murrurundi	Total
(No. responses)	(116)	(27)	(143)
Frequently	44.8	25.9	41.3
Occasionally	22.4	14.8	21.0
Rarely	32.8	59.3	37.8

$\chi^2 = 7.04$

Significance = 0.030 (2 degrees of freedom)

Cramers V = 0.22

Logical null hypothesis

H4 : Noise is not more noticed in mining regions.

For each of the five locations surveyed in the mining region the degree of annoyance and notice of trucks in relation to approximate heavy vehicle traffic figures were investigated and there did not appear to be any systematic variation in attitudes or perception with truck volumes. However, there is a trend which indicates that as the number of trucks increases they cause less annoyance to and are noticed relatively less by residents afflicted by the environmental problem.

TABLE 25 Contingency tables for attitudes and perception for the environmental problem of trucks on roads

	Location (%)		
Degree of upset	Broke Maison Dieu Ravensworth South Muswellbrook Warkworth	Murrurundi	Total
(No. responses)	(120)	(36)	(150)
Annoys a lot	60.0	41.7	55.8
Annoys a little	28.3	38.9	30.8
No feelings	11.7	19.4	13.5

$\chi^2 = 3.73$

Significance = 0.165 (2 degrees of freedom)

Cramers V = 0.16

Logical null hypothesis

H5 : Trucks are not more upsetting in mining regions.

	Location (%)		
Degree of upset	Broke Maison Dieu Ravensworth South Muswellbrook Warkworth	Murrurundi	Total
(No. responses)	(120)	(38)	(158)
Frequently	75.0	44.7	67.7
Occasionally	14.2	36.8	19.6
Rarely	10.8	18.4	12.7

$\chi^2 = 10.72$

Significance = 0.005 (2 degrees of freedom)

Cramers V = 0.30

Logical null hypothesis

H6 : Trucks are not more noticed in mining regions.

Overview of the three environmental problems

The following observations can be made about the specific problems of dust, noise and trucks:

dust —causes some loss of amenity at the locations of Maison Dieu and Ravensworth; and

—dustfall is most upsetting in regions of greatest levels;

TABLE 26 Contingency tables for attitudes and perception for the problem of trucks within a mining region

Degree of upset	Location (%) Broke Maison Dieu	 Ravensworth South Muswellbrook Warkworth	 Total
(No. responses)	(35)	(85)	(120)
Annoys a lot	65.7	57.6	60.0
Annoys a little	20.0	31.8	28.3
No feelings	14.3	10.6	11.7

$\chi^2 = 1.89$

Significance = 0.389 (2 degrees of freedom)

Cramers V = 0.13

Logical null hypothesis

H7 : Trucks are not more upsetting in regions of greatest truck densities.

Degree of	Location (%) Broke Maison Dieu	 Ravensworth South Muswellbrook Warkworth	 Total
(No. responses)	(34)	(86)	(120)
Frequently	73.5	75.6	75.0
Occasionally	17.6	12.8	14.2
Rarely	8.8	11.6	10.8

$\chi^2 = 0.64$

Significance = 0.726 (2 degrees of freedom)

Cramers V = 0.07

Logical null hypothesis

H8 : Trucks are not most noticed in regions of greatest truck densities.

noise —is experienced as an environmental problem significantly more in regions of mining activity than in non-mining regions;

trucks —are generally upsetting to people but are noticed the most by people in mining regions; and

—there does not appear to be any relation between heavy vehicle traffic volumes and attitudes towards these vehicles.

In summary, the most immediate environmental problem existing in the Upper Hunter Region is the problem of dust and it is attributable to open cut mining activities to a major extent. The locations of Maison Dieu and Ravensworth are the places suffering a loss of amenity from this environmental problem.

Effectiveness of the survey

The effectiveness of the survey is now examined. The major findings and resulting implications of these are contained in the next section.

Prior to commenting on the actual survey a few cautionary notes on attitude surveys in general should be made. Attitude surveys attempt to scientifically grasp essentially qualitative information relating to the feelings and beliefs of the sampled population. There are limitations in communicating questions, categorising and encoding responses, producing statistics from these and interpreting them in an unbiased manner. Throughout this study care was exercised to be as scientific as possible, though some of the above limitations will have influenced the results. Unfortunately such deficiencies characterise all attitude research.

Our survey proved to be an effective instrument in terms of achieving an assessment of attitudes to the environment of the Upper Hunter Region. A few basic deficiencies, however, became apparent during the analysis of responses which were not noticed during the analysis of the pilot survey at Cessnock. More specifically these were:

- for question 2—information as to whether the respondent's occupation was within/connected with/ disjoint from the mining industry/ coal utilisation activities was not specifically obtained. This produced some minor difficulties; and
- for questions 8 and 9—the examples cited in the questions were in retrospect poor choices, they were 'too-close-to-home' and would have biased the results obtained from these questions to some extent. This effectively prevented us being able to make observations with respect to the tradeoffs that may exist between environmental problems and infrastructure provision related to the mining industry.

Analysis of the survey responses would have been better facilitated by the greater use of questions incorporating forced choice type responses in preference to the open-ended variety. However, this would have narrowed responses. One of the key objectives of the survey was to ascertain what was uppermost in the minds of respondents. Otherwise no undue difficulties were met during the analysis.

Major findings

The findings of most significance are listed below:

- Employment opportunity associated with coal based activities was a key agent in attracting people into the surveyed area of the Upper Hunter Region.
- In general, provided there are no direct effects from mining, people enjoy the 'good environment' of the region. Environment in this context incorporates lifestyle factors in addition to true environmental considerations. In cases where there are perceived effects, such as Maison Dieu, Ravensworth and to a lesser extent Warkworth, the enjoyment is less.
- The likes and dislikes of people seem to be directed at either the mining activities or the poor provision of facilities.
- Respondents in Murrurundi, a town outside the mining region, have little complaint with mining activities.
- Of all the respondents surveyed including the control population, the five top rated environmental problems that upset people's enjoyment are: litter in recreational areas, litter on streets, river pollution, dust and trucks. The five most noticed problems happen to be the same problems, but in the order litter on streets, litter in recreational areas, trucks, dust and river pollution. There is a strong correlation between the attitudes people have to environmental problems and the degree to which they are observed.
- Males tend to be upset more by environmental problems than females and, with the exception of litter, tend to notice these problems more frequently though the differences are not significant to a large degree.
- Some environmental problems are perceived differently according to age. To a 5 per cent level of significance (based on the χ^2 statistic), young people are most upset by smoke and river pollution and old people are upset to a greater extent by noise. Differences in the degree of noticing environmental problems are not that significant but the trend is for older people to notice trucks more and notice odours and river pollution less than the young.
- People living in mining as opposed to non-mining areas notice smoke, trucks and noise significantly more. There is some reason to believe that smoke refers to haze or dust clouds at least part of the time.
- The five environmental problems directly affecting the surveyed populations are felt to be trucks, dust, smoking, street litter and noise with the last two being rated equally. There are some location specific differences. Respondents from Maison Dieu (on a no-through road)

rate trucks lower. Broke, Maison Dieu and Ravensworth residents rate noise higher. Populations from Broke, Murrurundi, South Muswellbrook and to a lesser extent Warkworth which are regions of greatest population density rate litter higher.

- Effects caused by environmental problems experienced by residents of the region are considered to be primarily of a nuisance value, such as being an annoyance or causing some degree of inconvenience. A smaller proportion of people suffer some hardship, such as extra cleaning through these effects, while causation or aggravation of an illness as a perceived effect is much less prevalent.
- Action taken by people affected by environmental problems to prevent a recurrence is minimal. Some preventative action is practised mainly by the respondents of Maison Dieu, Ravensworth and Warkworth (many of whom have devices such as air conditioners, water filters, clothes dryers in their homes). Complaints are highest from the populations of these three locations.
- The level of complaints previously registered seems to be disproportionately low compared to the stated degree of the experienced environmental problems in the survey.
- In general, respondents feel that the existing environmental problems can be solved and primarily delegate responsibility for this to the government or its departments and agencies.
- There seem to be no significant differences in health problems between the mining and non-mining regions. Apparent differences can be readily explained by differences of a demographic nature.
- There are no evident significant differences in the occurrence of bronchial problems for different dustfall levels.
- It is significant at the 1 per cent level that high levels of dustfall lead to strong feelings and at the 10 per cent level that dustfall is noticed more in regions where it is more severe.
- The locations of Maison Dieu and Ravensworth appear to experience sufficient dustfall to constitute an amenity loss as defined by the SPCC interim criterion of 4 g/m^2/month as an annual average. And it is in these areas that the level of complaints and distress is high. It appears that approximately 40–50 per cent of respondents possess strong feelings towards dustfall when the experienced levels are bordering on this threshold for amenity loss (see Fig. 10).
- It is significant at the 5 per cent level that noise is noticed more in mining as opposed to non-mining regions. Unfortunately there is no

data base available to relate the level of annoyance to the noise levels experienced.

- Trucks are noticed more in mining regions than non-mining regions at the 1 per cent level of significance. There does not seem to be any systematic variation between attitudes towards trucks and the volume of trucks experienced on roads.
- The results for the environmental problem of dust generally do not contradict the SPCC choice of a 4–10 g/m^2/month (annual average) dustfall guideline adopted as an interim criterion to gauge loss of amenity. However, given that the level of official environmental complaints is low when compared to the surveyed level of perception of dust, it may be that the threshold for amenity loss occurs at a lower level. On the other hand, the threshold is not likely to be as low as 2 g/m^2/month. This is roughly the level which occurred in South Muswellbrook, Broke and Warkworth at the time of survey and Table 23 shows that the residents of these locations notice and are annoyed by dust to about the same degree as the control group which endures normal rural levels.

Recommendations

Several deficiencies in available data have become apparent in our attempts to relate environmental risk to the level of 'pollution' from mining related activities. It is useful to point these out as follows.

- In view of the dustfall levels being quite high at both Ravensworth and Maison Dieu (and since at Warkworth; NSW SPCC 1983) it is important to obtain a comprehensive measure of the ambient levels of suspended particulates in those areas. This would allow the levels to be assessed for potential health effects, especially in the region of Ravensworth where sulphur dioxide levels are relatively significant and possible synergistic effects between particulates, sulphur dioxide and nitrogen oxides may occur. Of course, dichotomous sampling which differentiates between particles above and below a threshold size would be most useful.
- The absence of a data base for existing noise levels in the Hunter Region allows only qualitative assessment of this potential problem to be made. In view of this and the attitudes found towards noise, it would be useful to have some monitoring in progress, especially in trouble spots. This would allow some quantification of the impact of noise of various intensities.

- Correlation between dustfall rates and attitudes is strong (eg Fig. 9). However, a survey of other populations experiencing dustfall levels intermediate between those of Ravensworth/Maison Dieu and the other areas surveyed would clarify the relationship further. Information on perceptions and attitudes in such areas would provide more precise threshold data on the relationship between loss of amenity and dustfall levels.

4

Air pollution in the Upper Hunter Region due to large point sources

Introduction

Liddell power station is the only large point source of sulphur dioxide (SO_2) emissions at present operating in the Upper Hunter Region although the first stage of the nearby Bayswater power station was due to be commissioned in late 1985. The NSW Electricity Commission Report (1981–82) shows that the small emergency load station at Muswellbrook would have negligible effect on the SO_2 recorded. Its coal consumption in 1981–82 was 0.7 per cent of that of Liddell and its emissions would only affect the late 1981 readings since it did not operate in 1979–80 and 1980–81. The Liddell power station is a coal-burning facility designed to provide 2000 MW of electricity to the New South Wales grid. There are two stacks which each disperse wastes from two steam turbine generating units. The constituents of the boiler furnace exhaust emissions are derived directly from the basic elements which make up the coal. Along with nitrogen, oxygen and carbon dioxide these emissions are assumed in the Bayswater EIS (Electricity Commission of NSW 1979) to be sulphur oxides, nitrogen oxides and particulate matter (ash). In this chapter the effects of the latter group and fluoride emissions due to current and planned development in the area are assessed.

Before being discharged to the atmosphere the exhaust gases pass through particulate collection plants which remove a high proportion of particulates. However, there is no scrubbing of sulphur dioxide emissions as it is felt that, because the sulphur content of the coal is low (0.4–0.5%), the high stacks allow the gas to disperse sufficiently before reaching the ground leading to only low ground level concentrations.

This 'tall stack' philosophy is being repeated with Bayswater power station where, partly because the sulphur content of the coal used is expected to be higher (0.7–1%), the stacks used will be higher.

In particular, this chapter considers the observations collected by monitors in the area around Liddell power station and, where the data set is extensive enough, a statistical model is used to estimate maximum concentrations. Application of the statistical model also allows estimation of the number of times any given standard is equalled or exceeded. A mathematical dispersion model is invoked to relate emissions to ground level concentrations. An analysis of meteorological data collected in the area is undertaken in order to assess the effect of meteorological variations on recorded air pollutant levels. Finally we consider the future impact of power stations in the region. This includes the Bayswater power station currently under construction and the impact of other possible power stations located at three sites considered suitable by the NSW Electricity Commission.

From the analysis carried out in this chapter it is clear that only the SO_2 emissions and perhaps those for oxides of nitrogen from Liddell power station are of concern. Under 1980 and 1981 meteorological and emission conditions the resulting ambient concentrations have exceeded the short-term health standards adopted by some countries but none of the long-term standards. There appear to be negligible damage costs to vegetation and materials under these same conditions.

The effect of sulphur dioxide emissions

The location in the Upper Hunter Region of the Liddell power station and the monitoring stations used are shown in Fig. 12. The SO_2 levels to be expected and the influence of meteorology on these levels is considered in this section.

The data sets

The data sets used for sulphur dioxide have been provided by the State Pollution Control Commission while meteorological data have been made available by the NSW Electricity Commission. Two years of data are analysed: 1980 and 1981. The sulphur dioxide data come from six monitoring sites and the meteorological data from two weather stations, as shown in Fig. 12. Four of the SO_2 monitors lie approximately SE of the Liddell power station and the other two are approximately NW of the power station. One weather station is close to the power station and the other is on a tower on Mt Arthur which is approximately 6 km west and about 360 m above the power station.

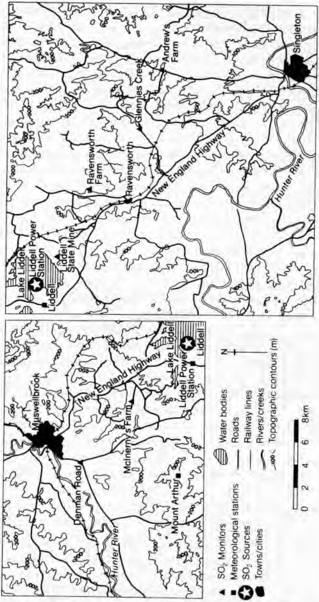


FIGURE 12 Positions of meteorological and sulphur dioxide monitoring stations to the north-west and south-east of Liddell power station

The meteorological stations record wind speeds and wind directions in the eight standard directions and these were provided as one hour averages. The meteorological records analysed cover the full two years of 1980 and 1981. The SO_2 results are recorded on a half-hourly basis over the period from April 1980 to December 1981 but, as shown in Table 27, the record lengths differ from station to station. There are also data sets supplied by the SPCC giving daily coal consumption at Liddell power station from 1.4.80 to 31.3.81 and daily total energy generation from 1.4.81 to 26.10.81. There are no comprehensive inversion data available for the area but inversion data have been analysed from records at the Williamtown air force base on the coast near Newcastle.

While the lengths of the data records for the SO_2 monitoring stations vary considerably, certain trends do become apparent when comparing these records. Fig. 13 illustrates the variation in the time series of monthly means for all six stations. Units of sulphur dioxide concentration are given in parts per hundred million (pphm). The four stations SE of Liddell Power Station show higher readings in winter than in summer while the two stations NW of the power station show higher readings in summer than in winter. The transitional seasons of spring and autumn show variable behaviour.

It is illuminating to consider the level of the variation in monthly energy production for Liddell power station during the period 1.4.80–26.10.81, as shown in Fig. 14. The data base used to obtain these results consists of either daily coal consumption figures or energy production figures but a conversion factor based on the NSW Electricity Commission Reports has been used to determine the variation in terms of daily energy production in gigawatt hours (GWhr). Both monthly means and peaks are shown in Fig. 14. As expected winter is the peak period for the time interval considered and summer is the lowest demand period. However, it is clear that the higher concentrations of sulphur dioxide monitored in 1981 compared to 1980 cannot be explained solely by the larger energy production. The effect of meteorology of the area on sulphur dioxide levels is shown to be significant in a later section.

Before considering such meteorological effects it is instructive to study the cumulative frequency distributions for SO_2 observations for each station. The results for the ½ hourly, 1 hourly, 3 hourly, 8 hourly and 24 hourly SO_2 data at Glennies Creek station are considered for the yearly period 1.11.80–30.10.81. This station has been considered as it has the most extensive record for that period. The plots of these observed distributions on an exponential probability scale are shown in Fig. 15.

TABLE 27 SO$_2$ record lengths and monitoring stations

Station	Distance from Lidell power station (km)	Direction from Liddell	Record length	Number of months with greater than 70% of data	Number of months with between 30% and 70% of data
Ravensworth Farm	9.6	SE	4.4.80–15.12.81	11	7
Glennies Creek	16.1	SE	24.4.80–30.10.81	12	6
McInerny's Farm	6.0	NW	9.8.80–15.12.81	5	3
Liddell State Mine	2.7	SE	24.5.80–29.10.81	5	2
Andrew's Farm	21.7	SE	6.9.80–27.10.81	3	4
Denman Road	13.5	NW	17.12.80–14.12.81	9	3

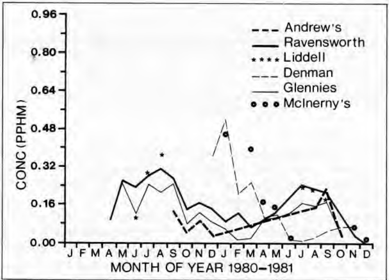


FIGURE 13 **Monthly mean measured SO$_2$ concentrations (pphm) at six monitoring sites; Andrew's Farm, Ravensworth Farm, Liddell State Mine, Denman Road, Glennies Creek, McInerny's Farm for months with at least 30 per cent complete records.**

Because an exponential distribution would plot as a straight line in Fig. 15 it is clear that an exponential distribution is a reasonable representation of such data (see Appendix V for more details).

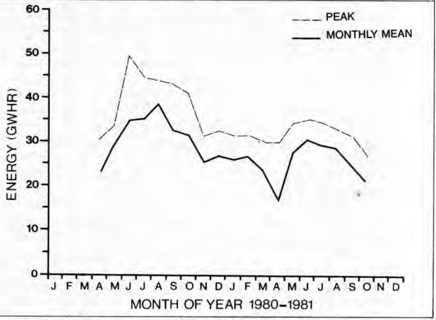


FIGURE 14 Variation of monthly mean and peak energy (GWhr) consumption for Liddell power station.

The estimates of maximum SO_2 concentrations using the exponential distribution are shown in Table 28 for all six stations following the method adopted in Appendix V. The advantage of a statistical distribution to represent pollutant observations is that it can be used to infer the entire pollutant data set over a period where records are missing but a reasonable sample is given. In Table 28 the fraction (f) of observations available for the six stations is shown. The derived maxima are calculated for data sets of the size indicated by this fraction so that the observed maximum may be compared with the maximum estimated from the statistical distributions. The exponential distribution predictions are in good agreement with the observations and it is assumed throughout this chapter that the SO_2 data sets can be well represented by exponential distributions.

The meteorological conditions

There have been several studies undertaken on the meteorology of the region (eg Bridgman 1980, Coleman and Sinclair 1979). The meteorological data examined here are considered only in order to relate the SO_2 levels to the wind data. No detailed statements are made about the meteorology of the area based on our analysis. However, the characteristics of the data are compared with other studies in order to determine whether the time period considered (1980–81) is abnormal or not.

Wind roses for these meteorological stations at Liddell and Mt Arthur are respectively presented in Figs. 16 and 17 for January and July of both 1980 and 1981. In January 1980 the predominant wind direction at Liddell is from the SE with significant winds from the E, W and NW; and in January 1981 the SE direction is again the predominant direction

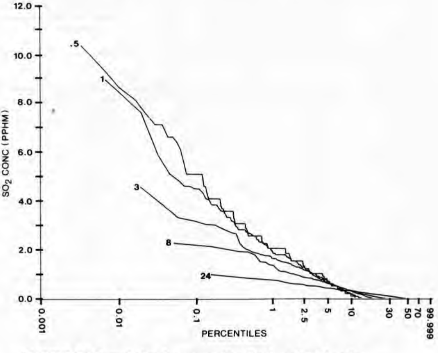


FIGURE 15 Cumulative frequency distributions for Glennies Creek SO_2 data (1.11.80–30.10.81) for ½ hour, 1 hour, 3 hour, 8 hour and 24 hour averages, plotted on an exponential scale.

with the only other significant direction being from the south. Mt Arthur is approximately 360 m higher than the Liddell site and the winds in January 1980 are predominantly from the S and N with some contributions from the W and SE; and in January 1981 the winds are predominantly from the S and SE. In July 1980 and 1981 the winds at Liddell are predominantly from the NW and N with the N direction dominant in 1981 and the NW direction dominant in 1980. At Mt Arthur the winds in both years during winter are predominantly from the W and NW with the N and S components significant in 1980. It is inferred from these wind roses that both topography and the Ekman spiral tend to channel the surface wind in the NW-SE direction along the valley.

TABLE 28 Comparison of observed maximum SO_2 in pphm (χ_O) and estimated maxima using the 2-parameter lognormal distribution (χ_L) and the exponential distribution (χ_E) for the period 1.11.80–31.10.81 (f = fraction of data available at each station and used in the estimates for the statistical distribution)

Time Av. (hours)	Max.	Denman Road	McInerny's Farm	State Mine
½	χ_O	7.5	16.0	9.5
	χ_L	13.1	33.0	11.4
	χ_E	10.0	21.3	9.7
	f	.72	.42	.30
1	χ_O	5.4	14.3	6.8
	χ_L	9.6	23.7	7.6
	χ_E	8.3	18.0	7.4
	f	.71	.42	.30
3	χ_O	4.3	9.2	3.0
	χ_L	5.7	12.8	3.2
	χ_E	5.7	12.2	3.8
	f	.71	.42	.29
8	χ_O	2.8	6.4	1.6
	χ_L	3.7	8.1	2.0
	χ_E	3.5	7.7	2.3
	f	.70	.41	.28
24	χ_O	1.65	2.4	.67
	χ_L	1.73	2.6	.75
	χ_E	1.64	2.7	.65
	f	.66	.38	.24

The wind roses for Liddell for January do not differ greatly from those found by Bridgman (1980) for Singleton and Muswellbrook in summer. The meteorological data sets compiled by Coleman and Sinclair (1979) for Liddell for the years 1971–79 indicate general agreement with our data for January though their winter wind roses indicate a stronger westerly component than that suggested by our July wind roses at Liddell. The wind roses of Bridgman for Singleton and Muswellbrook unfortunately relied on data using the Beaufort Wind Scale, which he himself regards as a highly subjective method. The data sets published by Coleman and Sinclair, however, are compiled by a Munro electrical contact cup anemograph at 8 m. The data used for Liddell here come from the same station and the data set for Mt Arthur is collected using an anemometer.

avensworth	Glennies Creek	Andrew's Farm
17.5	10.2	5.0
21.5	15.0	7.9
12.3	9.8	6.4
.63	.86	.24
11.0	8.8	4.5
12.6	11.5	5.4
9.7	8.2	5.3
.62	.86	.24
6.8	4.5	3.2
6.4	5.4	3.0
6.5	5.1	3.4
.62	.85	.24
3.4	2.2	1.6
3.9	3.3	1.4
3.6	2.9	3.0
.60	.85	.23
1.3	.91	.52
1.1	1.11	.52
1.2	1.01	.53
.55	.83	.20

The effect of wind on SO_2 levels

Given the wind behaviour described in the last section, it is clear that the six SO_2 monitoring sites shown in Fig. 12 lie along the dominant wind directions with respect to Liddell power station. The average

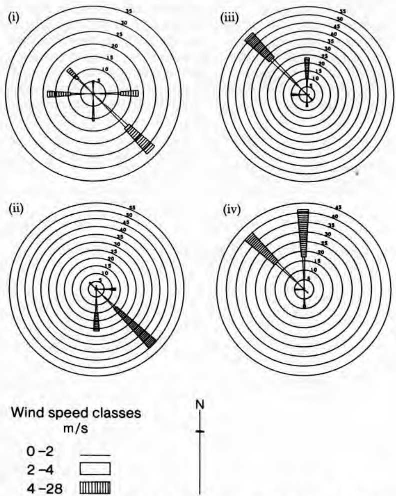


FIGURE 16 Wind roses for Liddell meteorological station for (i) January 1980, (ii) January 1981, (iii) July 1980, (iv) July 1981: showing the percentage of time the wind direction falls in the eight cardinal directions and the wind speed lies in one of the three classes.

diurnal variation in influential direction wind speed calculated from recordings at Liddell and the associated SO_2 data at the Ravensworth monitor SE and the Denman Road monitor NW of the power station are shown in Fig. 18 for January 1981 and July 1981. The figure demon-

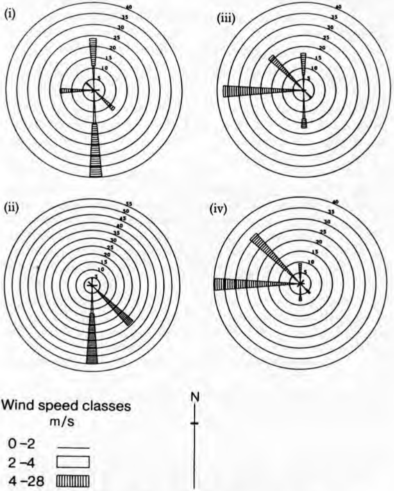


FIGURE 17 **Wind roses for the Mt Arthur meteorological station for the same dates as Fig. 16.**

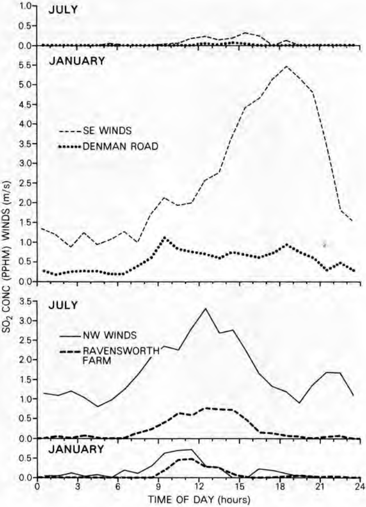


FIGURE 18 Diurnal variation of monitored SO_2 concentrations and influential wind speed direction for January and July 1981. The upper two graphs are for the Denman Road monitoring station lying to the NW of Liddell power station and winds originating from the SE. The lower two graphs are for the Ravensworth monitoring station lying to the SE of the power station and winds originating from the NW.

strates that stations NW of Liddell power station show higher levels on average in summer than in winter while those to the SE show the higher levels on average in winter.

An analysis of the meteorological and SO_2 data revealed that the individual monitors registered negligible SO_2 levels when the winds were blowing consistently over many hours from each monitor towards the power station. This indicated that there is no significant contribution at ground level to the recorded SO_2 levels due to long-range transport of SO_2 from elsewhere in the Hunter Region.

Another analysis was undertaken to check any local emission effects by considering hourly SO_2 data at each monitor when the wind is blowing directly from the monitor to the power station. An examination of the SO_2 records showed that hourly readings up to 4 pphm were recorded when the wind was blowing from the monitor towards the power station. Only on one day was it not the case that the wind had suddenly changed direction so that such readings could be easily explained by assuming they were due to recirculation of the power station plume on the ground. The one day concerned showed a reading up to 4 pphm at the State Mine monitor but nowhere else. This event therefore seemed to be due to local incineration of wastes in the vicinity of the monitor. By using statistical distributions to represent the data such rare events do not affect our assumption that the SO_2 levels recorded were due solely to Liddell power station.

Table 29 shows the mean wind speeds recorded at Liddell meteorological station from 1.1.80 to 31.12.81 and the mean meteorological values for 1971–76 compiled by Coleman and Sinclair (1979). There appears to be a significant variation from 1980 to 1981 when compared to 1971–76 data. The months of 1980 began with lower winds than those to be expected from 1971–76 data but then there were very high winds towards the end of 1980. However, in February 1981 the winds were very low. From then on, throughout 1981 the winds generally were about average. In particular, the mean monthly wind speeds in the winter of 1980 are lower than in 1981.

Given these seasonal effects and the differences between 1980 and 1981 annual behaviour, it is useful to compare, where possible, SO_2 concentrations in similar seasons in 1980 and 1981. As mentioned earlier, the data records for some stations are scattered (see Table 27) and tend to be concentrated in certain seasons. Given the length of the SO_2 record (1.4.80–31.12.81) it is only possible to compare the two winter periods in 1980 and 1981 but not the two summer periods.

Bridgman and Chambers (1981) have shown that extreme levels are found at all stations for any season. Nevertheless, since higher levels on average occur NW of the power station in summer and to the SE in winter, the statistical analysis concentrates on the four stations SE of the power station in winter and the two to the NW in summer. An examination of the data in Table 27 shows that the monitoring program carried out also gives this emphasis. Assuming an exponential distribution for the SO_2 data, the estimated SO_2 maxima for the ½ hour, 1 hour, 3 hour, 8 hour and 24 hour time average data are given in Table 30 for winter 1980 and 1981, and in Table 31 for summer 1980–81.

TABLE 29 Mean monthly wind speeds for Liddell (km hr^{-1})

	Mean		1971–76**		
Month	1980	1981	Mean for 1971–76	Max. monthly value for 1971–76	Min. monthly value for 1971–76
January	10.72	15.37	16.54	18.97	14.69
February	19.70	6.02	14.88	16.58	12.68
March	7.82	12.19	10.31	14.36	5.52
April	5.43	11.42	12.61	16.81	9.61
May	9.53	11.83	12.06	13.98	8.68
June	11.47	14.89	11.39	13.89	8.15
July	13.47	14.51	13.39	17.43	8.45
August	12.27	16.58	14.24	20.49	7.73
September	16.29	12.80	12.03	15.00	7.25
October	14.43	12.16	15.86	17.66	13.80
November	18.51	11.85	14.55	16.77	12.33
December	17.16	*	15.27	16.20	13.02

* Not enough data available for reliable analysis

** Coleman & Sinclair (1979)

The results in Table 30 indicate that the levels recorded in 1980 were higher than in 1981 at all stations for which there are data. These results are partly explained by Fig. 14 which shows the variation in monthly energy output from April 1980 to October 1981. The maximum daily value for each month is substantially higher for the winter months in 1980 than in 1981. The Annual Reports of the NSW Electricity Commission for 1981 and 1982 indicate that one of the four power units was out of operation in 1981 from March to November which would account for the change shown in Fig. 14. From the Electricity Commission Reports the coal consumption for 1981–82 was 50 per cent of that in 1980–81 but then two more power units went out of operation at Liddell in November 1981 and 'from that point on it was necessary to cope with a situation in which 1500MW of capacity was shut down for an extended period' (Electricity Commission of NSW Annual Report 1981–82).

Since the period studied here extends to the end of October 1981, it is assumed that the power station was operating at 75 per cent of the 1980 capacity from March to October 1981. With the reported maximum MW load sent out in 1981–82 being approximately 73 per cent of that in 1981 this appears to be a reasonable assumption. Therefore the changes in SO_2 levels from winter 1980 to winter 1981 which are of the order of a factor of 2 would be unlikely to be solely due to the effect of change in emissions. The meteorological variation from one year to the next should account for part of the change and the results of Table 30 indicate that such effects may be quite significant.

TABLE 30 Estimates for four stations SE of power station of maximum SO_2 level in pphm (χ_m) using exponential distribution for winter (1.6–31.8) 1980 and 1981 compared with the observed maximum (χ_O) from limited data sets (f = fraction of data available but estimates are for the full winter period)

Time av. (hours)	Max.	State Mine 1980	State Mine 1981	Ravensworth 1980	Ravensworth 1981	Glennies Creek 1980	Glennies Creek 1981	Andrew's Farm 1980	Andrew's Farm 1981
½	χ_O	8.5	6.5	17.5	7.8	14.0	8.5	–	4.0
	χ_m	9.9	9.2	15.3	8.8	12.4	8.9	–	5.3
	f	.70	.67	.81	.46	.66	.94	–	.27
1	χ_O	7.4	5.5	11.0	5.2	10.0	5.8	–	3.8
	χ_m	8.4	7.0	12.7	6.8	10.0	7.4	–	4.1
	f	.70	.67	.81	.46	.66	.94	–	.27
3	χ_O	5.4	3.0	4.5	4.6	4.4	4.5	–	1.7
	χ_m	5.2	4.4	7.1	5.0	5.0	4.6	–	2.5
	f	.69	.64	.81	.43	.66	.92	–	.25
8	χ_O	3.4	1.6	3.1	2.5	2.8	2.2	–	1.2
	χ_m	3.2	2.5	4.1	3.3	4.2	3.7	–	1.7
	f	.69	.62	.80	.39	.66	.93	–	.24
24	χ_O	1.4	–	1.0	.88	.93	.73	–	.43
	χ_m	1.5	–	1.2	1.2	1.1	.87	–	.66
	f	.67	–	.78	.28	.66	.91	–	.21

TABLE 31 Estimates for two stations NW of power station of maximum SO_2 levels in pphm (χ_m) from exponential distribution for summer (1.12–28.2) 1980–81 compared with observed maximum (χ_O) from limited data sets (f = fraction of data available but estimates are for the full summer period)

Time Av. (hours)	Max.	McInerny's Farm	Denman Road
½	χ_O	16.6	7.5
	χ_m	21.1	9.2
	f	.49	.79
1	χ_O	14.3	5.4
	χ_m	22.9	7.6
	f	.48	.79
3	χ_O	9.4	4.1
	χ_m	8.5	3.4
	f	.44	.78
8	χ_O	6.4	2.8
	χ_m	8.5	3.4
	f	.44	.78
24	χ_O	2.4	1.7
	χ_m	3.5	1.6
	f	.39	.74

Mathematical models

During intensive study periods in the region in August 1980 and February 1981, various meteorological parameters were measured. These parameters enabled the implementation of a model by Chambers *et al* (1982) to simulate SO_2 concentrations emanating from Liddell power station. The model is of the typical Gaussian plume form and is described in detail in Appendix VI. We have used this model to predict maximum downwind SO_2 concentrations at the monitoring sites. The model predictions are compared with the statistical estimates of these maxima in Table 32.

The calculation of these model predictions involved using a data set of Bridgman and Chambers (1981). Therefore the winter values of SO_2 emission rate and power level for each stack chosen for the calculations were 1.75 kg s^{-1} and 850 MW, respectively, and for summer, 1.58 kg s^{-1} and 530 MW respectively. The agreement between the estimated and predicted maximum SO_2 levels shown in Table 32 is to within a factor of 2, an accuracy to be expected by a model of this type.

The variation of maximum SO_2 values with distance is also shown in Table 32 together with the wind speed values at which these are predicted to occur. The highest SO_2 levels are predicted to occur between 5 and 7 km from the source in both winter and summer, in agreement with the observed behaviour found by Bridgman and Chambers (1981) during the intensive study period. This also agrees with the results of the previous section. The critical wind speed values at which these are predicted to occur are shown in Table 32 and are all of the order 10–12 ms^{-1} in both winter and summer. From the wind rose data shown in Figs. 16 and 17 it is clear that such levels are only to be expected mainly to the SE, S and E of the power station. In summer, however, there is a possibility of high levels occurring in most directions lying between 5–7 km from the power station, with the highest probability of such occurrences being to the N, NW and W of the power station. From both the summer and winter wind roses it also appears unlikely that high levels NE or SW of the power station will occur very often.

TABLE 32 (a) Comparison of model predictions and statistical estimates for maximum hourly SO_2 values in pphm for winter (June, July, August) 1980 and summer (December, January, February) 1980–81.

(b) Variation of maximum SO_2 values with distance and wind speed values (u) at which these occur.

(a)

	Winter		Summer	
Station	Estimate	Model prediction	Estimate	Model prediction
State Mine	8.4	4.0	—	—
McInerny's	—	—	22.9	10.5
Ravensworth	12.7	9.2	5.3	9.0
Denman Road	—	—	7.6	7.2
Glennies Creek	10.0	6.6	3.2	6.2

(b)

Distance (km) from source	1.0	2.0	5.0	7.0	10.0	15.0
Winter max SO_2	0.01	1.5	9.4	10.0	9.0	7.0
critical wind speed*	2.0	2.0	10.1	12.7	17.2	19.9
Summer max SO_2	0.03	2.7	10.5	10.2	8.8	6.6
critical wind speed*	5.5	6.3	9.5	12.3	17.1	19.9

*The model predictions are restricted to the range $2 \leq u < 20$ ms^{-1}

It is not possible to use such a model to reproduce here cumulative frequency distributions of SO_2 observed at the six stations. Although the model predicts the location and position of the maximum, the model results in general do not agree well with observations. An example of this is shown in Fig. 19 where the winter 1980 (1.6.80–31.8.80) SO_2 readings at Ravensworth of 1 hour values between 10.00 am and 3.00 pm are compared with the model results. Clearly there is little similarity between the model and observations.

There are a number of reasons for this disparity. First the wind direction data have only been supplied for the 8 cardinal directions so that the only wind direction considered is from the NW. Then the model predicts levels directly downwind of the station whereas the wind direction meanders substantially so the model predictions are mainly overestimates. It is noticeable, however, that the maximum levels are comparable. These results will be considered more closely later where the effect of inversions will be investigated.

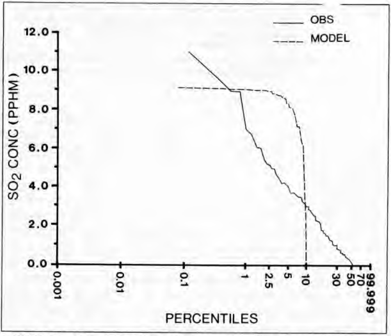


FIGURE 19 The comparison of observations for winter 1980 hourly SO_2 observations at Ravensworth between 1000–1500 hours and the model predictions using Q = 1.75 kg sec^{-1}, power = 850 MW, inversion height = 1000 m

Consequently, it is not possible to accurately forecast the number of times a standard is exceeded using any frequency distribution produced solely by the Gaussian plume model. Fortunately this is not a problem here as it is clear from the work in the next section that the levels are not currently high enough for standards to be exceeded more than a few times a year. Therefore model predictions of maximum levels and the location of possible 'hot spots' are enough to determine likely consequences of SO_2 levels for this region.

The results of such a model indicate that the air pollution maxima occur between 5–7 km from the power station. The high levels on average would occur in the NW-SE wind direction so the 6 stations should be well placed to record levels representative of the highest occurring in the region. Therefore the results of the statistical models which enhance these monitored data may be used to estimate the likely health and damage effects of SO_2 from the power station.

Air quality standards and damages to health, vegetation and materials

There are numerous air quality standards adopted by different countries in relation to ambient concentrations of SO_2. Table 33 lists the standards adopted by the USA, Japan, Canada and West Germany (also see Appendix I). It is pertinent to analyse the SO_2 levels produced for the Upper Hunter Region in relation to such standards.

Tables 30 and 31 show that the maximum SO_2 levels in summer 1980–81 occurred at the McInerny site and at Ravensworth in winter 1980, that is between 6–10 km from the power station as found by Bridgman and Chambers (1981). The maximum levels recorded at these two stations are shown in Table 34 and comparison with Table 33 reveals that only the short time-average standards of some countries are exceeded. The short-term 1 hour standard of Japan is exceeded at both stations. Also, according to statistical estimates, the desirable short-term 1 hour standard of Canada is exceeded at McInerny's Farm. Since only 49 per cent of the data is available at McInerny's Farm then the estimate of the maximum would be accurate only to within a factor of 2 and the number of times a standard is equalled or exceeded less accurate than that. Nevertheless the results at Ravensworth for which 81 per cent of the ½ hourly data were available indicate that firstly, the results for McInerny's Farm are accurate enough to determine which standards would be violated; and secondly, the total number of times adds up to 1–2 per cent of the summer period. It is also clear that there is a potential for the long-term 24 hour standard of Japan of 4 pphm to be exceeded.

Health. It should be noted that SO_2 standards for health are often presented together with standards for suspended particulates (SP), as the particulates are seen as carriers of sulphur dioxide into the lungs. There has been no analysis of SP data here. The results in Table 34 indicate that this needs to be done to fully determine how close the region is to exceeding health standards adopted by other countries.

TABLE 33 Ambient air quality standards for SO_2

	Long-term standard		Short-term standard	
Country	Level (pphm)	Averaging time (hours)	Level (pphm)	Averaging time (minutes)
Canada —Maximum acceptable level	11	24	34	60
—Desired level	6	24	17	60
Japan	4[1]	24	10	60
U.S.A.	14[2,3]	24	—	—
	50[2,4]	3	—	—
West Germany	20	24	30[5]	30
WHO	8[6]	24		

1 Average of hourly means for 24-hour value Annual = 3 pphm
2 Not to be exceeded more than once per year
3 Primary standard in U.S.A.
4 Secondary standard in U.S.A.
5 Short-term standard not to be exceeded more than once in 2 hours in West Germany
6 98% of observations to be below this figure

Unfortunately, most of the available particulate data for the region are in the form of deposition levels and any comprehensive information on ambient concentrations will have to come from future monitoring and modelling exercises. It is still useful, however, to consider the literature which reports results of the effects of SO_2 and particulates on health.

There is a fair amount of information available on the long term effects of SO_2 levels. In fact, Ferris (1978) has concluded that the present US Standards appear reasonable for long-term effects. The US Standards are 3 pphm for mean annual 24 hour SO_2 concentrations and 75 μgm^{-3} for annual geometric mean 24 hour particulate concentrations.

TABLE 34 Maximum SO_2 levels (in pphm) observed, χ_O, estimated, χ_m, and the number of times N^* a standard is equalled or exceeded at Ravensworth (Winter 1980) and McInerny's (Summer 1980-81)

		Time average (hours)			
		½	1	3	24
Ravensworth (81% of ½ hourly data available)	χ_O	17.5	11.0	4.5	1.0
	χ_m	15.3	12.7	7.1	1.2
	N^*	—	6	—	—
	(Country**)		(Japan)		
McInerny's (49% of ½ hourly data available)	χ_O	16.0	14.3	9.4	2.4
	χ_m	21.1	22.9	14.2	3.5
	N^*	—	61	—	—
	(Country)		(Japan) 5 (Canada)		

* N is calculated from exponential distribution for the total winter or summer period.

** The country for which the standard in Table 33 is exceeded.

On the other hand, he also notes that there is not much information on short-term effects. Asthmatics are one of the most sensitive groups and one study by Cohen *et al* (1972) indicates increased frequency of attacks at 7.6 pphm SO_2 and 150 μgm^{-3} particulates. The above association is, however, considered a weak one because cold weather was also a correlated factor. Another group is noted to conclude tentatively that small reversible changes in pulmonary function could be detected between mean daily levels of 7.6 and 11.5 pphm of SO_2 but the relative contribution of the associated daily particulate level of 230 μgm^{-3} could not be separated out. Ferris (1978) also cites one study where effects have been noted and these occur either above or close to the present US Standard. Finally, another cited study showed no effect at levels considerably above the standard.

Since the maximum predicted levels of SO_2 from our results are no more than 3.5 pphm for a 24 hour average, the above evidence indicates that present SO_2 levels in the Upper Hunter Region constitute a comparatively low health risk to the general community. This conclusion requires, of course, that particulate levels are not inordinately high in comparison to SO_2 levels.

It appears that the biggest problem areas for particulates in the Upper Hunter Region are in the vicinity of the open cut coal mines. For example, the Electricity Commission has provided a few months of TSP data for an area about 10 km SE of the power station and these indicate that concentrations can be near the US Standard of 75 μgm^{-3} for sites about a kilometre away from the mine pit. The Ravensworth SO_2 monitor which was set up to record maximum SO_2 concentrations in the area is about 1½ km to the NE of this area.

It is pertinent to analyse the above levels by reference to a series of studies in New Hampshire by Ferris and others (see Ferris 1978). It seems that when SO_2 levels are low (less than 1.4 pphm), increased particulate levels can be tolerated. They report no change in respiratory symptoms or pulmonary function over two periods where the particulate concentrations were 131 μgm^{-3} and 80 μgm^{-3}. It is certain that both 1980 and 1981 annual SO_2 levels in the Upper Hunter average out to under 1 pphm for 24 hour samples.

Of course, the very important consideration of particle size is absent from most available information on the effects of SO_2 and particulates and little particle size analysis has been undertaken in the Hunter Region. It is now generally agreed that particulates less than 15 μm are the inhalable sizes which lead to the more serious health damages, and it is only recently that proposals for a new US primary standard, applying to particles less than 10 μm or 15 μm, have been placed before the US Clean Air Scientific Advisory Committee (Hileman 1981). Then again it is usually aerosols with diameters between 0.1 and 1 μm that affect the lungs (Natusch and Wallace 1974) so further discrimination of dust samples may be necessary.

Vegetation. The expected damage to plants of different sensitivities to air pollution is also of interest. Table 35 shows the upper and lower limits of plant damage for different sensitivities at a 5 per cent level of injury compiled by Stern (1977). It is clear from Table 35 that there are no damages to be expected from the ½ hour and 1 hour values observed or estimated in the region. However, the observed and estimated maximum 8 hour values are shown in Table 35 and indicate a potential for damage at the 5 per cent level of injury for sensitive plants.

To investigate this further it is necessary to consider specifically the vegetation targets in the area where these maxima occur. There are some open woodland areas remaining but most of the well vegetated land is native or improved pasture, and some is under crops. A convenient and extensive summary of much of the literature describing effects on specific plants is given in Irving and Ballou (1980). There are definite trends in the results presented there which allow vegetation groupings. These are now discussed.

TABLE 35 Concentrations of short-term SO_2 exposures producing 5 per cent injury to vegetation grown under sensitive conditions

	SO_2 levels (pphm)					
	½ hour		1 hour		8 hour	
Plant sensitivity	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit
Sensitive	400	100	250	50	75	10
Intermediate	1000	350	750	200	200	50
Resistant		> 900		> 700		> 150
Observed 8 hour SO_2 maximum level (6 km NW) = 6.4 pphm						
Estimated 8 hour SO_2 maximum level (6 km NW) = 8.5 pphm						

Species like rye, lucerne, oats and wheat require levels of 4.7 pphm over their entire growing season to suffer a reduction in yield. It is almost certain that native pasture is more resistant than the species within this category. Almost all vegetables have a threshold injury level above 45 pphm for a 3 hour average, and to obtain yield reductions, levels of 1–7 pphm must be sustained throughout the growing season. Grapevines receive chronic injury at 26 pphm over a 24 hour period and suffer a reduced yield when subjected to 13 pphm over a prolonged period. It is safe to say that all these criteria are well above the maxima experienced in 1980 and 1981 in the Upper Hunter Region.

Materials. Potential SO_2 damages to materials in the Upper Hunter Region include the following: tarnishing and corroding of metals, discolouration and leaching of building materials, discolouration and softening of paint finishes and reduction in the strength of textiles.

Significantly, most experiments on material effects are performed at much higher dose levels than those encountered presently in the area of this study. For example, exposures between 10 and 100 pphm were given to a range of paint types. However, 10 pphm does not produce significant erosion rate increases over clean air exposures (see Stern 1977). Stern (1977) also shows that at low to medium oxidant levels the effects of SO_2 on corrosion of steel exposed for 10 years level out below 2 pphm. In fact high levels of oxidant are known to inhibit corrosion by SO_2. Even with textiles the concentrations required for damage are higher than current ambient concentrations. Zeronian (1970) and Zeronian *et al* (1971) report the relevant results. Over a 7 day period, loss in strength for a range of cotton and rayon fabrics exposed to clean air averaged 13 per cent while fabrics exposed to air containing 10 pphm SO_2 averaged 21 per cent. However, experiments on man-made fibres—nylon, polyester and modacrylic—showed that exposures of 20 pphm only affected nylon fabrics, losing 80 per cent strength in the SO_2 affected atmosphere and 40 per cent in clean air.

As in the case of health damages, most of the potential receptors of material damage are in the towns of Muswellbrook, Singleton and Denman where SO_2 ambient levels are expected to be lower than the maximum levels given in Table 34. It appears from the available literature that a daily maximum below 10 pphm rules out the possibility of measurable damage to the major susceptible material types. The 1980–81 estimated 24 hour maximum from Table 34 is 3.5 pphm.

The effect of other emitted air pollutants

The other air pollutants emitted by Liddell power station and considered in this section include the oxides of nitrogen, particulate matter and fluorides.

Oxides of nitrogen

The Electricity Commission of NSW (1979) states in the EIS on Bayswater power station that 'for a station operating in a manner similar to Liddell, the concentration of oxides of nitrogen (expressed as $\mu g/m^3$ N.T.P. NO_2) are approximately 0.7 times that of sulphur dioxide (expressed as $\mu g/m^3$ N.T.P. SO_2)'. Saw (1983) suggests that the ratio of sulphur dioxide emissions and those of oxides of nitrogen is closer to unity. Given these two factors, the range of expected values of the maximum levels of oxides of nitrogen are shown in Table 36. These results are obtained using the estimated sulphur dioxide maxima in Table 31 for McInerny's Farm which has the highest readings of the six monitors. The range of values shown is obtained by using both the factors 0.7 and 1.0 to convert the sulphur dioxide statistical estimates.

The NHMRC standard for a 1 hour maximum for nitrogen dioxide (NO_2) is 17 pphm or approximately 333 μgm^{-3}. The expected 1 hour maximum NO_X (oxides of nitrogen) level given in Table 36 is 600 μgm^{-3}. When NO_X emissions leave the stack it is likely that most of the gas is nitric oxide (NO) and this is eventually transformed into nitrogen dioxide (NO_2) via the reaction with oxygen in the atmosphere.

TABLE 36 Maximum expected levels of oxides of nitrogen, particulates, and fluorides at McInerny's Farm

Time average (hours)	Oxides of nitrogen* (μgm^{-3})	Particulates* (μgm^{-3})	Total fluoride* (μgm^{-3})
1	420–600	90	5
3	260–372	56	3
8	156–223	33	2
24	64– 92	14	1

* Calculations assumed 26.2 pphm = 1 μgm^{-3} of sulphur dioxide at 25°C.

It is not clear what the ratio of NO_2/NO is when the plume reaches the ground 7–10 km from the stack. For a weak wind of 2 ms^{-1} the plume should still be able to reach a 7 km site in about an hour. It would seem that short-term NO_X concentrations should be closely monitored given these results.

Particulate levels

In the Bayswater power station EIS the NSW Electricity Commission (1979) indicates that an emission rate of 0.25 gm^{-3} N.T.P. be used for particulate matter from each of the two stacks at Liddell power station. The Commission notes that results obtained when using such a rate should be 'conservatively high estimates'. The Electricity Commission also quotes a design gas flow rate for each of the Liddell power station stacks of 1320 m^3s^{-1} at an exit temperature of 123°C. Therefore a conservatively high emission factor for particulates for the Liddell power station would be approximately 0.188 gm^{-3}. This should be compared with the emission factors suggested by Saw (1983) of 1.28 kg of particulates per tonne of coal used. The total coal consumption for 1980–81 financial year by Liddell power station was approximately 5.35 x 10^6 tonnes (NSW Electricity Commission Annual Report 1981) so the average emission rate for particulates using Saw's value is 0.22 kg s^{-1}. Using the gas flow rate of 1320 m^3s^{-1} and the emission factor of 0.188 gm^{-3} suggested by the Electricity Commission the estimate of the emission rate is 0.25 kg s^{-1}: approximately the same as that of Saw. These results should be compared with the sulphur dioxide emission rate of 1.58–1.75 kg s^{-1} for the intensive study period.

If it is assumed that all the particulate matter emitted is suspended particulates then the particulates may be treated as a gas and estimates of the particulate levels may be found by multiplying the sulphur dioxide levels by a factor of 0.25/1.67, (using the Electricity Commission's emission rate for particulates and the mean of the sulphur dioxide emission rate found in the intensive study period) or 0.15. Of course, under this assumption the highest particulate levels due to power station emissions would occur at the same place as the sulphur dioxide maxima, namely 5–10 km from the power station. The estimates of the maximum SP levels calculated on this basis are shown in Table 36. Since we have assumed that all the particulates emitted may be treated as fine particulates these results should be overestimates of the maxima. As with oxides of nitrogen, the range of results shown in Table 36 are obtained using the maximum SO_2 levels for McInerny's Farm in Table 31. The results of Table 36 indicate that, compared to the USEPA 24 hour maximum standard of 260 μgm^{-3} adopted by the SPCC as a guideline, the maximum expected SP emissions from the power station lead to negligible ground level concentrations.

Bridgman (1986) has suggested that the relationship between SO_2 and particulate concentrations should clarify when a current study around Lake Munmorah is complete.

Fluorides

Although the Electricity Commission of NSW does not mention emissions of fluorides as a potential problem to be considered, gaseous and particulate fluoride measurements have been recorded in the region by the SPCC. These measurements have been recorded at some of the stations used to record sulphur dioxide levels. The stations are McInerny's Farm and Denman Road NW of the power station, and Ravensworth Farm and Glennies Creek SE of the power station. The records are weekly totals (gaseous and particulate) and are shown in Fig. 20 for the period 20.2.81 to 20.5.82, although the records are incomplete and sometimes the monitors have been moved (which is indicated by different curves for the same station).

Saw (1983) has estimated an emission coefficient of 0.076 kg per tonne of feed coal for fluorides. Given his estimates for sulphur dioxide of 9.5 kg per tonne this means that the estimated sulphur dioxide levels should be multiplied by 0.008 to obtain the associated hydrogen fluoride concentrations. These estimates are shown in Table 36 and once again the range shown is obtained using the estimated SO_2 maxima at McInerny's Farm in Table 31. These levels refer to gaseous and particulate fluoride. Saw (1983) believes the size of most particulates is less than 5 μm. Even making the conservative assumption that all the fluoride is of the gaseous variety most harmful to plants the levels are only at the bottom of the range of values which cause 5 per cent injury to sensitive vegetation types (eg Stern 1977, Chapter 4 and Appendix I).

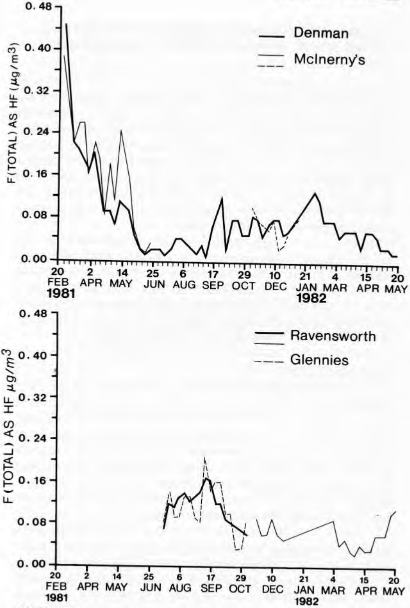


FIGURE 20

(a) Weekly levels of total fluoride concentrations for stations NW of Liddell power station (Denman Road, McInerny's)

(b) to the SE at the bottom (Ravensworth, Glennies Creek)

The expected future air pollution levels due to Liddell power station in different meteorological conditions

The results so far have summarised the air pollution levels in the Upper Hunter Region for the time period from 1.4.80 to 31.10.81. This was the period for which SO_2 data were available for analysis and the time for which the model used by Chambers *et al* (1982) was calibrated. However, there are dangers involved in summarising the air pollution impact of Liddell power station based on such a short meteorological record. Chapter 5 elaborates by considering more extensive data sets for the Newcastle area. In fact the conclusions in Chapter 5 indicate that there are problems in basing air pollution impacts on such short meteorological data sets as considered here.

There is a need to consider both meteorological and air pollution data sets for a longer period of time. This course of action is strongly recommended using earlier records of the SPCC and the NSW Electricity Commission. However, there are some speculative estimates which may be made by extending the modelling work of Chambers *et al* (1982) to the record of inversion heights available for the Williamtown air force base 20 km north of Newcastle near the coast.

A trapping model

The work of Chambers *et al* (1982) using a Gaussian plume model indicated that the maximum SO_2 levels due to Liddell power station would occur approximately 5–7 km from the power station. This result is confirmed by the statistical analysis of the SO_2 data from the six monitoring stations, a result which should be approximately correct for any year considered as it is largely a function of the design characteristics of the stacks at Liddell power station. However, as indicated previously, although the model is fairly accurate in determining the location of the maximum it usually underestimates the maximum by up to a factor of 2.

Chambers *et al* (1982) consider this problem in their construction of adequate mathematical models for SO_2 emissions from Liddell power station. Their work indicates that the maximum SO_2 levels are probably due to classic 'trapping' conditions. A brief description of the trapping model used by Chambers *et al* is given in Appendix VI. In essence trapping conditions occur when the plume has stayed aloft overnight beneath a subsidence inversion and when the sun rises and begins to heat the atmosphere beneath the inversion the plume is brought to the ground. This 'fumigation' may be prolonged for a number of hours if the subsidence inversion persists and this persistent fumigation is referred to as trapping.

The level of pollution in such conditions is critically dependent on the height of the subsidence inversion. Therefore it is possible to conjecture about the frequency and seriousness of such episodes by considering the frequency of occurrence of low level subsidence inversions. Unfortunately there are no comprehensive inversion data available for the Upper Hunter Region. However, Chambers *et al* (1982) have indicated that at least two trapping episodes occurred during the intensive study periods, two weeks in each of August 1980 and February 1981. They found that the trapping model developed by the Tennessee Valley Authority (TVA) for the power stations in that area gave a reasonable estimate of the SO_2 levels for inversion heights of approximately 900 m in the area around the power station. Although the levels predicted by the model were comparable to observations the model could not accurately estimate the location of where that peak level occurred. The location of the maximum in such conditions was accurately predicted by the standard Gaussian plume model they employed even though that model underestimated that maximum by a factor of 2.

The TVA model was developed by Montgomery *et al* (1973) who found that such trapping conditions occurred up to 30 to 40 days per year in the Tennessee Valley Region. Clearly such work suggests that a concerted effort is required to record inversion heights in the Upper Hunter Region. Lacking such a data set we have considered instead inversion data at Williamtown near Newcastle.

The inversion data at Williamtown

The inversion data at the Williamtown air force base from 1958 to 1982 have been compiled by Dixon (1984). The inversions are recorded in the morning, and sometimes in the afternoon, at Williamtown by radiosonde balloon flights. It is assumed that these inversions are due to synoptic scale weather patterns which span both the Newcastle and Upper Hunter Regions.

The inversion readings at Williamtown corresponding to those readings in the Upper Hunter when hourly SO_2 levels above 10 pphm were recorded are shown in Table 37. There is little correspondence between low inversion levels and high concentrations. If the subsidence inversions do span both the Newcastle area and the Upper Hunter Region then the inversion heights at the Upper Hunter can be approximated by those at Williamtown by subtracting the height of the Liddell power station region above that of Williamtown (the difference is approximately 130 m). Even with this correction there is little correlation between low inversion heights and high SO_2 levels. In fact, for the two days on which Chambers *et al* (1982) report definite subsidence inversion heights in the Upper Hunter (approximately 900 m on 10.8.80 and 800 m on 17.2.81) there are either no inversions recorded at Williamtown (10.8.80) or only a weak afternoon inversion (17.2.81) (see Table 37). Certainly such results do not give much confidence in applying the Williamtown inversion data directly to the Upper Hunter Region. However, it may be that the use of such data is if anything conservative in predicting such trapping episodes.

The number of inversions per month at 0900 hours and 2100 hours for 1980 and 1981 at Williamtown are shown in Table 38 for different classes of heights. The totals for each year are given in Table 39 for morning inversions and 40 for afternoon inversions. The SO_2 results analysed earlier correspond to the period April 1980 to October 1981. Table 39 shows that there were only 9 mornings in 1980 when the inversion heights at 0900 hours were below 1000 m, and only 7 mornings in 1981. Given the requirement that the wind is blowing directly towards the monitor during trapping conditions it is possible that the SO_2 data sets used here do not contain many, if any, such extreme events.

The results in Table 39 do indicate that at 0900 hours 20–40 inversions per year may occur at Williamtown below 1000 m. For synoptic weather patterns these results would be applicable to the Upper Hunter Region. The worst year in the period was in 1960 where 37 morning inversions at 0900 hours occurred at a height of less than 1000 m.

The results for the 'afternoon' or pm readings are shown in Tables 38 and 40 from 1963 to 1981. Table 38 shows that in 1981 only 3 inversions below 1000 m occurred and that all three occurred in February. There are 9 inversions in 1980 below 1000 m but from Table 38 none occurred in winter when much of the recordings were concentrated. In 1964 and 1966, however, more than 14 such inversions occurred.

While the results in Tables 38 and 40 are strictly valid for Williamtown alone, it is probable that the 1980–81 period studied here would on average in the Hunter allow better dispersive conditions than in other years. Such results do suggest that morning subsidence inversions below 1000 m may occur up to 40 times per year in the Upper Hunter and over 10 per year in the afternoon. This high frequency argues for an estimate to be made of the effect of such inversions if trapping conditions occur.

TABLE 37 Comparison of hourly SO_2 readings above 10pphm and the inversion readings at Williamtown

Station	SO_2 levels (pphm)	Inversion heights (m) 9.00 am	3.00 pm	Date (Time in hours)
McInerny's Farm	12.3	1684	—	9.8.80 (1600)
	10.5	917	1388	25.12.80 (1000)
	12.0	917	1388	25.12.80 (1100)
	11.5	—	1620	1.1.81 (1300)
	10.5	—	1620	1.1.81 (1400)
	14.3	1784	—	17.2.81 (1800)
Ravensworth Farm	11.0	2069	—	17.7.80 (1200)
	11.0	1069	—	11.11.80 (1100)
Glennies Creek	10.0	—	—	5.8.80 (1200)

— indicates that no subsidence inversion has been recorded.

TABLE 38 (a) The number of 0900 hour inversions for 1980 and 1981 from Williamtown records for different height classes specified in m (see also Dixon, 1984)

Number of morning inversions for 1980

Class	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
<500	1	0	0	0	0	0	0	0	0	0	1	0	2
500– 750	0	0	1	0	1	0	0	0	0	1	1	1	5
750–1000	0	0	1	0	0	0	0	0	0	0	0	1	2
1000–1250	1	0	2	1	1	0	2	1	1	1	1	1	12
1250–1500	2	3	3	1	1	0	1	3	3	1	2	1	21
1500–1750	0	3	0	1	1	1	1	1	3	3	1	1	16
1750–2000	1	3	0	2	1	1	1	0	0	0	3	3	15
>2000	1	9	3	7	3	5	3	5	3	5	3	2	49

Number of morning inversions for 1981

Class	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
<500	0	0	0	0	0	0	0	0	0	0	0	0	0
500– 750	0	0	0	0	0	0	1	1	0	1	0	0	3
750–1000	0	1	0	0	0	1	0	1	0	0	0	1	4
1000–1250	2	0	1	0	0	1	1	0	1	0	1	1	8
1250–1500	1	0	0	0	0	0	3	1	0	0	1	1	7
1500–1750	1	0	2	2	7	0	0	0	1	0	1	2	16
1750–2000	1	1	2	0	1	0	0	0	1	0	1	0	7
>2000	1	2	5	2	2	1	6	1	3	0	1	3	27

(b) The number of 2100 hours inversions for 1980 and 1981 from Williamtown records for different height classes specified in m

Number of afternoon inversions for 1980

Class	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
<500	0	0	0	0	0	0	0	0	0	0	0	1	1
500– 750	1	0	0	0	0	0	0	0	0	0	2	2	5
750–1000	0	0	2	0	0	0	0	0	0	1	0	0	3
1000–1250	0	2	1	2	0	0	0	0	0	0	0	0	5
1250–1500	1	2	0	2	0	1	1	0	0	1	3	1	12
1500–1750	1	4	0	2	1	1	1	1	0	1	2	1	15
1750–2000	0	2	0	1	0	0	0	2	0	0	1	0	6
>2000	0	3	3	1	3	2	4	5	6	4	3	1	35

Number of afternoon inversions for 1981

Class	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
<500	1	0	0	0	0	0	0	0	0	0	0	0	1
500– 750	1	0	0	0	0	0	0	0	0	0	0	0	1
750–1000	1	0	0	0	0	0	0	0	0	0	0	0	1
1000–1250	0	0	0	0	0	0	1	0	0	0	0	0	1
1250–1500	1	1	0	0	1	0	0	1	0	0	0	0	4
1500–1750	2	1	3	2	1	1	2	1	0	0	1	0	14
1750–2000	0	1	2	2	2	0	3	3	0	0	0	0	13
>2000	1	2	3	2	4	3	5	3	2	0	5	4	34

The results using the trapping model of Chambers *et al* (1982) (see Appendix VI) for trapping inversion heights of 500, 750 and 1000 m are shown in Fig. 21 for Liddell power station in winter conditions. The wind speed was assumed to be 2 m/s. For the given inversion heights, the trapping model yields maxima of 62 pphm, 28 pphm and 16 pphm, respectively. The corresponding results using the Gaussian plume model of Chambers *et al* (1982) without trapping yield maximum levels of 15 pphm, 10 pphm and 10 pphm for inversion heights of 500 m, 750 m and 100 m, respectively. As pointed out, the Gaussian plume model can be used accurately to reproduce the location of the maxima which is approximately 7–10 km from the power station. Clearly these hypothetical levels give cause for concern given our analysis on the health effects if fine particulate levels are also high.

Given all the approximations and assumptions used in arriving at the values shown in Fig. 21, these results should certainly not be considered as providing an accurate estimate of the consequencies of trapping of SO_2 emissions under subsidence inversions. However, these results do suggest a definite need to obtain comprehensive information on inversion heights in the Upper Hunter Region. Such work becomes even more critical when considering the likely effect of Bayswater power station and other power stations planned for the region.

Future air quality levels due to additional large point sources

The Bayswater power station is the only major new development in the Upper Hunter Region which can be viewed as another major point source of air pollutant emissions in the short term. In this section we attempt to estimate the impact of this power station on air quality levels. Since the Upper Hunter Region may also provide the site of other power stations (Electricity Commission of NSW 1979), the effects of such potential developments are also assessed here. It is convenient to restrict

TABLE 39 The number of 0900 hours inversions at Williamtown from 1958 to 1981 for different height classes specified in m (see also Dixon 1984)

	Class							
Year	<500	500–750	750–1000	1000–1250	1250–1500	1500–1750	1750–2000	>2000
1958	8	6	10	7	14	21	18	68
1959	9	5	4	8	7	15	16	94
1960	17	13	7	10	11	22	16	82
1961	7	7	6	8	13	10	11	78
1962	4	4	2	4	12	17	10	50
1963	9	3	2	7	9	10	13	64
1964	11	7	6	12	16	16	30	34
1965	14	9	7	9	14	20	24	77
1966	9	10	9	7	15	13	25	74
1967	4	2	5	6	8	9	18	103
1968	2	1	5	12	10	18	17	59
1969	2	3	0	7	4	11	15	39
1970	1	4	8	6	11	12	10	57
1971	3	1	3	3	10	17	17	48
1972	6	4	10	6	10	18	23	65
1973	7	7	6	6	9	8	12	77
1974	4	5	7	8	12	13	15	102
1975	2	6	8	18	17	19	23	87
1976	4	4	3	8	4	20	12	83
1977	3	3	5	5	8	13	16	70
1978	5	2	4	2	7	10	13	39
1979	8	4	9	6	14	11	16	43
1980	2	5	2	12	21	16	15	49
1981	0	3	4	8	7	16	7	27

our attention initially to sulphur dioxide as it has been shown that conversion factors (of sulphur dioxide to particulates, hydrogen fluoride and nitrogen oxides) may be used to extend the analysis to other pollutants.

TABLE 40 The number of 2100 hours inversions at Williamtown from 1963 to 1982 for different height classes specified in m (see also Dixon 1984)

	Class							
Year	<500	500–750	750–1000	1000–1250	1250–1500	1500–1750	1750–2000	>2000
1963	3	1	2	1	7	4	8	60
1964	9	3	2	4	7	13	12	61
1965	4	2	4	4	7	8	8	67
1966	9	1	4	10	5	3	12	78
1967	3	3	2	3	5	11	9	90
1968	0	2	1	3	7	6	7	54
1969	0	0	4	1	2	8	10	33
1970	1	0	3	2	4	6	10	55
1971	2	0	2	3	2	7	11	77
1972	2	2	1	6	7	12	10	78
1973	6	4	0	1	2	7	7	75
1974	7	1	1	4	4	7	15	76
1975	3	7	2	9	7	21	22	73
1976	6	2	3	2	5	7	10	89
1977	4	5	8	7	3	8	13	62
1978	4	0	0	1	4	4	8	32
1979	5	5	1	3	4	6	13	30
1980	1	5	3	5	12	15	6	35
1981	1	1	1	1	4	14	13	34

The effect of emissions from Bayswater power station

It is seen in Fig. 22 that the Bayswater power station is only a few kilometres from the Liddell power station. Our analysis here shows that the site chosen is the best site possible for minimal impact on ambient air quality levels from power station emissions. This is because significant overlap of the plumes from both stations occurs only when the wind is blowing in the least probable direction.

The stack characteristics of the station as detailed in the Bayswater EIS prepared by the Electricity Commission of NSW (1979) are shown in Table 41. The emission rate of SO_2 shown is based on the assumption that the plant is operating at 70 per cent annual capacity which is 'considered a high estimate of future station duties'. The final SO_2 emission rate is then derived using the SO_2 emission factor of Saw

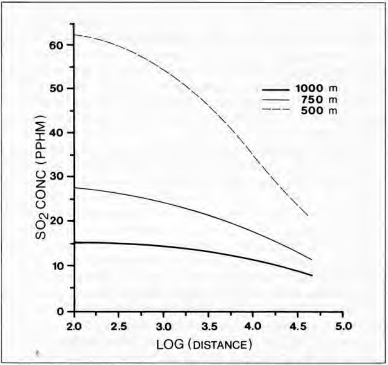


FIGURE 21 Predictions of hourly SO_2 levels using the trapping model for inversion heights of 500, 750 and 1000 m and the winter emission factor of $Q = 1.75\ kgs^{-1}$

(1983) of 19 kg/tonne of coal of 1 per cent sulphur content, which the EIS states as the maximum expected sulphur content of the coal used at the station.

The mathematical model used to estimate the impact of the Bayswater SO_2 emissions is the plume model applied by Chambers *et al* (1982) for Liddell power station. This model has been calibrated for Liddell power station and we feel that a similar intensive study to the one undertaken for Liddell power station in August 1980 and February 1981 should also be carried out when Bayswater power station is in operation. Until such a study can be carried out, only the best available mathematical model can be used to estimate theoretically the change in air quality due to the presence of the Bayswater power station.

Appendix VI shows that the model uses a formula for plume rise which is close to the general plume rise formula of Briggs (1975) and uses dispersion parameters derived by Carras and Williams (1983). The latter have been shown to be applicable in the Upper Hunter Region as well as at Mt Isa in Queensland and Kalgoorlie in Western Australia. So the meteorological effects critical in determining the behaviour of the emissions from Bayswater power station should be estimated by the model to a reasonable first approximation. However, model validation during an intensive study period is still warranted as mathematical models are not accurate enough to allow complacency about the results presented here.

Using the mathematical model given in Appendix VI to estimate the maximum combined effect of Bayswater and Liddell power stations yields some intriguing results, as shown by the pollution contours for SO_2 in Fig. 22. First the plumes from the two power stations do not yield additive concentrations in the major NW-SE directions since the plume characteristics are estimated to be too narrow for such additive effects in this direction. In general, the maximum SO_2 concentrations registered at each monitoring site in the major NW-SE direction occur when the wind is blowing directly at each site from Bayswater power station. These levels are slightly higher than the levels obtained when the wind is blowing directly from Liddell power station but only marginally so. Therefore the subsequent impact of Bayswater power station along the major NW-SE wind direction is approximately the same as that described earlier due to Liddell power station. Thus there is no damage to agriculture or materials and only a possibility of the violation of the more conservative short time-average health standards adopted by some countries. The effect of other emissions such as particulates, oxides of nitrogen and fluorides can be estimated in a similar way to that given for Liddell power station. Hence the same impact is probable, that is little effect due to SP and fluoride emissions but perhaps a problem due to NO_x emissions.

TABLE 41 Stack characteristics and emissions used to simulate Bayswater power station emissions

Stack height (2 stacks)	250 m
% Sulphur content of coal used	1.0 (max. design)
Flow (m^3/sec/stack)	2010
Temperature of gas at stack exit (°C)	130
Exit velocity of each stack (m/sec)	23
Maximum coal consumption per year (tonnes)	7.0×10^6
Emission strength* for both stacks (kg/sec)	2.9

* Based on 70 per cent of total coal consumption each year (ie 4.9×10^6 tonnes).

The only wind directions for which the plumes from the two power stations are found to be additive are in the NE-SW direction, as shown in Fig. 22. The description of the meteorological conditions prevalent in the area makes it clear that the NE-SW direction is the least probable wind direction in the area. This can be demonstrated by looking at the 1980 and 1981 wind roses shown in Figs. 16 and 17 for Liddell and Mt Arthur weather stations respectively. Therefore the estimated doubling of SO_2 concentrations shown in Fig. 22 for the NE-SW wind directions would be a rare event. Running the model with all wind speeds equally probable in all directions yields maximum SO_2 1 hour levels of approximately 20 pphm along the NE-SW axis. However, since this direction is least probable we have used the actual wind speed data for 1980 and 1981 to see how probable such a result would be in these conditions. The contours have been drawn from output of the Gaussian plume model used by Chambers *et al* (1982). The wind speed data input was from the Mt Arthur meteorological station and the wind direction data was from the Liddell station for the years 1980 and 1981 between 1000 and 1600 hours. The time period, 1000–1600 hours, is the period when the assumption of a well-mixed layer is the most probable. The Mt Arthur wind speed should be representative of the mean wind in such a mixed layer. Because of the channelling effect of the valley the Liddell meteorological station wind directions have been chosen. Therefore Fig. 22 should give the expected levels from both power stations for the meteorological conditions prevalent for 1980 and 1981. The maximum predicted level is 20 pphm so that the result is the same as that obtained by allowing all wind speeds to be equally probable in all directions. This agreement indicates that, although the NE-SW direction is least probable, conditions do occur which yield the maximum level possible.

It has been argued that the Chambers *et al* (1982) model predicts the location of 'hot spots' quite accurately which are at 5–7 km from both power stations in the NE-SW direction. The frequency of occurrence of the highest level can be estimated from the Liddell meteorological station wind rose data sets. An examination of the Liddell hourly wind roses for 1980 and 1981 for the period 1000–1500 hours shows that the wind blows in the SW or NE direction only 0.5 per cent of the time in 1980 and 1.5 per cent of the time in 1981. These results would give an upper limit to the frequency of occurrence of the highest levels shown in Fig. 22 for 1980 and 1981. In 1980 the frequency of calms between 1000 and 1500 hours was approximately 2.3 per cent with little data missing while in 1981 it was approximately 0.8 per cent with 8.4 per cent of the data missing. Taking a conservative view, trapping conditions in 1980 and 1981 may have occurred in the NE-SW direction about 2–3 per cent of the time. The trapping model results suggest that the highest levels may be up to a factor of 2 to 3 times higher than those shown for the 'hot spots' in Fig. 22. This strengthens the case for a study to estimate inversion heights in the region as well as measuring the corresponding SO_2 levels.

It cannot be assumed that the Gaussian plume model of Chambers *et al* (1982) will yield accurate results outside the period of 1000–1500 hours. Drainage flow effects at night and sea breeze effects late in the afternoon (for example see Hyde *et al* 1982) probably introduce a complicated windshear structure which the model is not designed to handle. Also marked windshear effects at night in stable conditions may introduce difficulties. Therefore estimated annual mean levels may not be very accurate using the model. For isolated sources such as power stations it is unlikely that long term concentrations will be significant except in the NW-SE direction and during the day. Normally the most serious effects of such power stations will be due to short-term high pollution 'episodes', that is concentrations over a 1 hour to 3 hour time period.

The Bayswater EIS (Electricity Commission, 1979) details results using the TVA Gaussian plume model. The model results reveal that the highest expected ground level concentrations occur when the wind is blowing from the SW in agreement with our results. The maximum 3 hour level found there was 480 $\mu g/m^3$ N.T.P. or 18.3 pphm, again quite comparable to our estimate of 16 pphm. The EIS also states that for a day when the worst conditions prevail for air pollution levels (with the wind blowing from the SW) the 24 hour average is 120 $\mu g/m^3$ N.T.P. or approximately 4.6 pphm. This is significantly below the USEPA and WHO standards of 14 pphm and 7.6 pphm, respectively. The predicted 1 hour SO_2 level of approximately 20 pphm in the Bayswater EIS agrees with our results also. This indicates that the Japanese 1 hour standard of 10 pphm will be violated. However, for a 24 hour period, it would be expected that the power station plumes stay aloft at night-time and air pollution ground level concentrations would only be significant during the day. Most of the SO_2 standards for such time averaging periods are therefore of interest, especially the 3 hour USEPA health standard of 50 pphm which has been used in Mt. Isa as the level above which smelting operations are curtailed (Neale 1980).

The work presented in discussing sulphur dioxide emissions argues that such high pollution episodes will most likely occur between 1000–1500 hours. Therefore the results in Fig. 22 should indicate the most probable location of such 'hot spots'. However, given the conjecture about trapping events, the estimated maximum 1 hour level of 20 pphm and 3 hour level of approximately 16 pphm (using the correction factor of Turner 1970) are likely to be underestimated by a factor of 2 or possibly more. Taking a conservative viewpoint it would appear that serious trapping conditions could possibly occur more than 10 times a year in the afternoon. This figure is based on the results in Tables 24 and 25 which show the probability of 0900 and 2100 inversions less than 1000 m to be of the order of 10 to 40 times per year. The frequency of winds in the NE-SW axis and of calm conditions between 1000–1600 hours is of the order of 2–3 per cent per year based on 1980 and 1981 meteorological data ie up to 7–12 days per year. It is therefore most probable that trapping conditions which occur about 5 per cent of the time (10–20 days per year) will take place when the wind is blowing in the most probable direction (NW-SE). So the concentration to be expected then will be due to one of the power stations which, given Fig. 21, may reach significantly high levels. The least probable occurrence will be in NE-SW direction with a probability of approximately 0.01 per cent or 3-4 times per year. However, the levels in such cases could lead to high air pollution episodes.

It should be noted that the wind rose information used (Figs. 16 and 17) categorises wind directions into 8 cardinal directions. The 2–3 per cent noted for NE-SW winds refers to the NE and SW sectors (each 45° in extent). The maximum levels referred to here only occur when the Bayswater and Liddell power stations are directly in line which should occur even less frequently than the 2–3 per cent noted for the sectors. This percentage must therefore be the absolute upper limit for 1980 and 1981.

The effect of more power stations

The Bayswater power station EIS states there are 'four unit power station sites in the Central Hunter, which would utilise cooling towers, and which could possibly be developed for commercial operation in 1985'. These are:

Bayswater
Whites Creek
Upper Saddlers Creek
Ponds Creek.

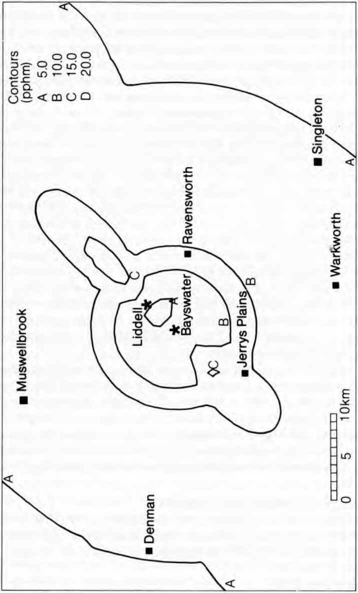


FIGURE 22 Contours of the maximum SO_2 levels due to both Bayswater and Liddell power stations, using 1980–81 wind roses between 1000 and 1500 hours.

The Bayswater EIS also states that 'having regard for the large reserves of coal in the area between Singleton and Muswellbrook and the availability of water from the Hunter River catchment, it is expected that one or more of the alternative sites will be developed at some time in the future'.

The possible effect of putting a power station identical to Bayswater at each of the three sites has been considered here. A map of the area with the sites is shown in Fig. 23. Given the simulation results the two most preferred sites on the basis of air pollution impacts are the Upper Saddlers Creek site and the Ponds Creek site as shown in Figs. 24 and 25, respectively. The addition of a third power station to Liddell and Bayswater in fact does not lead to an increase in the highest level estimated (using the Gaussian plume model of Chambers *et al* 1982). Once again, the plumes of the power stations are too narrow for more than two plumes to be additive at any one time. And the addition of two plumes only occurs when a receptor site is located directly downwind of two aligned power stations. Nevertheless, the model simulations reveal that the addition of a third power station to Liddell and Bayswater will cause a measurable increase in air pollution in most areas.

The Whites Creek site (Fig. 26) is the least preferred on air pollution grounds not because the 'hot spot' level is higher (in fact it is the same) but because the levels in Muswellbrook are significantly higher. Hence more people will be affected in this case. A site at Upper Saddlers Creek affects Denman more while a site at Ponds Creek affects Jerrys Plains more, both of which have similar populations. Of these two sites, probably the Ponds Creek is more preferred on air pollution grounds as the highest levels occur when the wind is blowing along the NE-SW direction which is 2–3 per cent of the time based on 1980 and 1981 figures. The Upper Saddlers Creek site would probably lead to the highest levels when the wind is blowing from the east which is 5–10 per cent of the time given the wind rose information in Figs. 16 and 17. The increase in the frequency of occurrence of winds blowing towards a population centre should increase the probability that extreme trapping conditions may affect a significant number of people.

If two power stations are to be located at two of the three given sites then Upper Saddlers Creek and Ponds Creek sites are preferred on air pollution grounds as fewer people are affected than if the Whites Creek site is chosen for one of the power stations.

It should be stressed that the values for SO_2 pollution in Figs. 24, 25 and 26 are based on the assumption that the new power stations are of

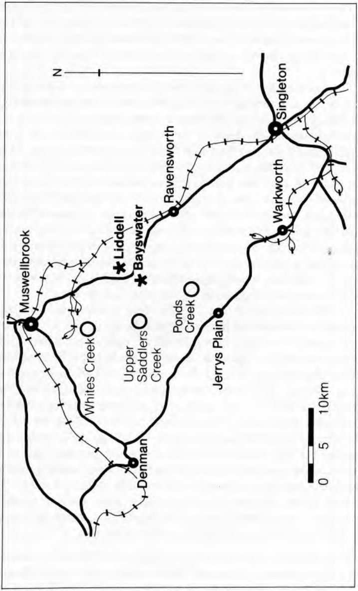


FIGURE 23 The location of the Upper Saddlers Creek, Ponds Creek and Whites Creek sites with respect to the towns in the area

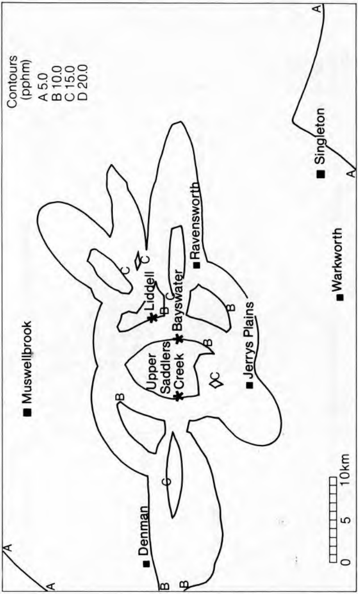


FIGURE 24 As in Fig. 22 but with a third power station exactly the same as Bayswater power station at Upper Saddlers Creek

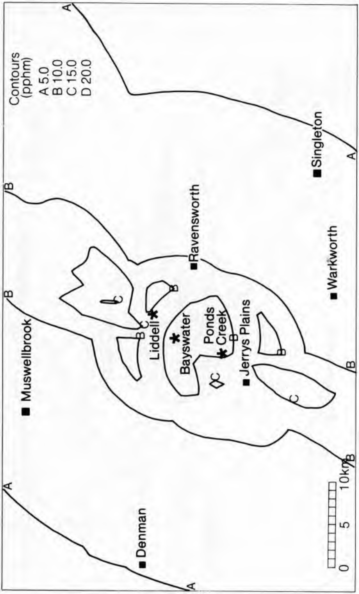


FIGURE 25 As in Fig. 24 but with the third power station at Ponds Creek

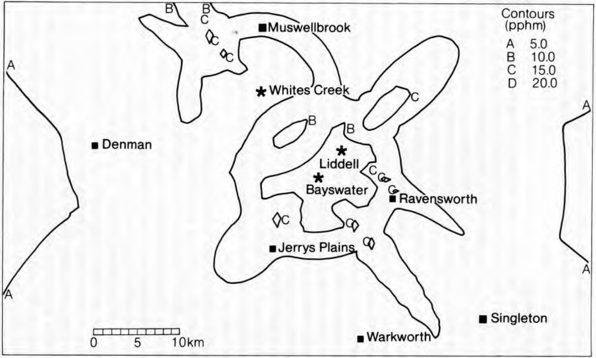


FIGURE 26 As in Fig. 24 but with the third power station at Whites Creek

the same design as Bayswater. Clearly the levels could be reduced with appropriate new construction designs such as taller stacks or wet scrubbing of SO_2.

Conclusions

In this chapter the impact of the emissions of air pollutants from Liddell power station has been considered initially. It was found that only the SO_2 emissions and possibly NO_x emissions are of concern. The effect of NO_x is more approximate as no NO_x readings are available. The results argue that the monitoring of NO_x should be seriously considered.

The analysis of ambient SO_2 concentrations for the 1980–81 period reveals that only the more conservative short-term health standards of some countries for SO_2 were violated. These violations could only be considered a health problem if the corresponding suspended particulate levels were also high. It has been shown that the particulate emissions from Liddell power station lead to very low SP levels. On the other hand the maximum SO_2 levels probably occur approximately 5–7 km from the power station so that areas near the dust-producing open cut coal mines in that vicinity may record relatively high SO_2-SP episodes over a 1 to 3 hour period during the day. In general, such episodes would not violate the USEPA 3 hour standard of 50 pphm (used in Mt Isa, for example, as a level above which smelting operations are curtailed). However, there is some uncertainty about the effect of serious trapping conditions in the area.

The highest estimated value for 1 hour SO_2 concentrations is 23 pphm and for 3 hours it is 14 pphm. Such estimates are based on statistical distributions which may overestimate the maximum by a factor of 2. Trapping conditions may account for such levels. A consideration of inversion data at the Williamtown air force base on the coast near Newcastle for the years 1958–1982 indicates that inversion may occur at heights below 1000 m over the region 20–40 times per year leading to significant trapping effects. This work shows that a sufficiently extensive study is needed to estimate the frequency of such inversions in the Upper Hunter Region. It would be used to investigate if higher levels than those recorded so far for the area are possible. Concurrent SO_2 monitoring is desirable in order to calibrate a trapping model which can then be used to estimate the extreme levels to be expected when trapping conditions occur.

The effect of emissions of air pollutants from the new Bayswater power station have also been considered. In terms of air pollution effects the site of this power station is found to be probably the best of those sites examined. The major reason for this is that the only wind directions along which the plumes of both Liddell and Bayswater power stations combine are within the NE and SW sectors, which are the least likely wind directions in the area. The addition of the Bayswater power station leads to 'hot spots' in this direction approximately 5–7 km from the nearest power station. A mathematical model used by Chambers *et al* (1982) to model the dispersion of SO_2 emissions from Liddell power station has been used in these calculations. Such a model probably yields a reasonable first approximation of the ground level concentrations. On the other hand the model accuracy is such that an intensive study similar to that described by Chambers *et al* (1982) for Liddell power station emissions is necessary once Bayswater power station becomes operational.

The model results estimate the highest 1 hour SO_2 level to be approximately 20 pphm during the day and approximately 16 pphm for 3 hour levels. The conditions associated with these maxima possibly occur with a frequency of the order of 20 days per year given our wind direction data. However, the model results probably underestimate the maxima by up to a factor of 2 as estimates of the effects of trapping conditions indicate much higher values. Trapping conditions probably occur 1–2 days per year when the plumes from the two power stations combine. Once again the need for a study to estimate inversion heights for the area is underlined.

Simulation exercises for additional power stations of exactly the same emission design as Bayswater power station have also been undertaken. The sites of Whites Creek, Upper Saddlers Creek and Ponds Creek mentioned in the Bayswater power station EIS as possible future sites were chosen and the same mathematical model used for Liddell power station was used to predict the air pollution effects. Our results indicate that the maximum level will not increase beyond that of the combined effect of Liddell and Bayswater power stations but levels in general will rise. The two sites at Upper Saddlers Creek and Ponds Creek are preferred on air pollution grounds to that at Whites Creek as fewer people will be affected by the increased pollution. Of these two sites, Ponds Creek is preferred as the high levels should occur less frequently. Once again the need to record inversion levels in the area in order to estimate the effect of trapping conditions on the SO_2 levels is required.

Therefore recommendations for future work in order of priority are as follows:

- Measurements of suspended particulate concentrations (especially for particles with diameters between 1-15 μm) in the populated areas near open cut coal mines and 5-10 km from the power stations.

- Measurements of inversion heights and frequencies for the Upper Hunter Region.
- An intensive study period similar to the one carried out for Liddell power station emissions to commence once Bayswater power station becomes fully operational.
- The monitoring of NO_x levels in the same areas as in the first point.

5

Air quality in Newcastle and the effects of meteorology

Introduction

In Chapter 4 evidence was presented that air quality levels may change dramatically from year to year as meteorology changes. In this chapter analysis will be undertaken on data sets of air pollutants in Newcastle dating from 1972 and on meteorological data sets commencing from 1951. From the analysis of such an extensive data set the influence of long-term meteorological effects on air pollution levels can be appreciated. The results indicate that a number of problems can arise if environmental effects are estimated using only a few years of data as has been the case in the Upper Hunter Region.

Newcastle contains a number of manufacturing industries giving rise to the emission of air pollutants. The SPCC (NSW State Pollution Control Commission 1980b) has classified the potential major pollutants in the area as:

- sulphur oxides—from the iron and steel industry, aluminium and other metal smelters, fertiliser producers and other energy intensive industries;
- fluorides—from aluminium smelters, chemical industries, iron and steel industry, and brickworks; and
- particulate matter—from ore handling, iron and steel manufacture and aluminium smelters.

Mechanisms for the long range transport of air pollution to Newcastle from power stations both in the Upper Hunter and to the south of Newcastle have been postulated by Dixon (1984). It is outside the scope of this report to investigate such mechanisms given the current information available. Clearly an extensive study needs to be carried out to enhance the information. In this chapter it is assumed that the air pollution levels in Newcastle are due to local industry but it is acknowledged that this assumption needs investigation. Under this assump-

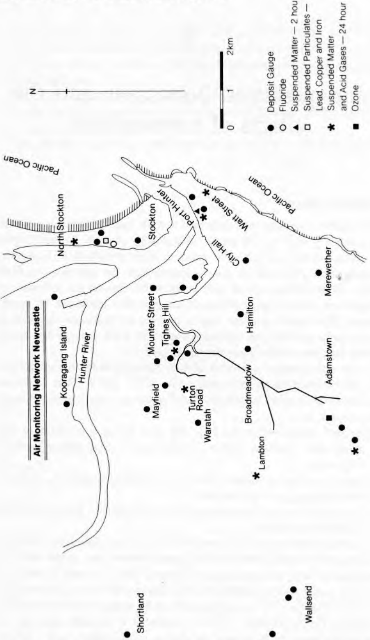


FIGURE 27 Newcastle area with air pollution monitoring network

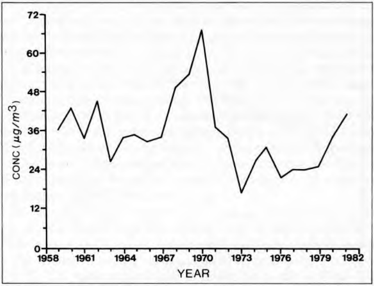


FIGURE 28 **The average annual mean acid gas 24 hour readings at City Hall, Watt St and Mounter St for 1959–81**

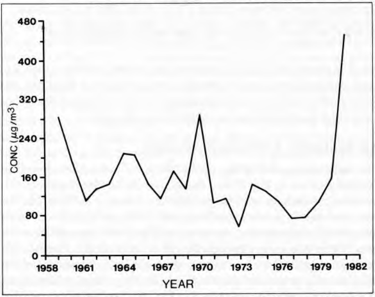


FIGURE 29 **The average maximum acid gas 24 hour readings at City Hall, Watt Street and Mount Street for 1959–81.**

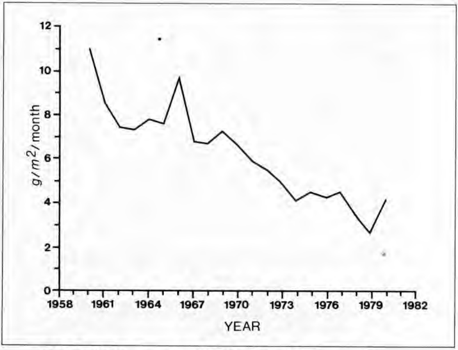


FIGURE 30 The mean insoluble dust deposition rates at 20 Newcastle stations for 1960–80

tion it is shown that if WHO standards are not to be violated then acid gas emissions should not be allowed to rise. On the other hand, the area may be able to tolerate some increase in fine particulate emissions but not in total particulate load as dustfall levels are high.

Air pollution levels in Newcastle

The monitoring network set up by the SPCC and Newcastle City Council is shown in Fig. 27 and the stations are listed in Table 42. The air quality guidelines used by the SPCC are shown in Table 43. For three stations acid gas data have been collected since 1958 (Moore 1982) and the annual average and maximum acid gas levels averaged for these three stations are shown in Figs. 28 and 29 respectively. The acid gas data are expressed as 24 hour average concentrations of acid gas and the average annual means are shown in Fig. 28; the average maximum 24 hour levels for each year are shown in Fig. 29. The SPCC has adopted the WHO annual mean standard for acid gas of 60 μgm^3 as a guideline and it is clear from Fig. 28 that this standard has been exceeded in the past. Throughout the 1970s the levels fell but the early 1980s produced some rise in levels. In this chapter it is shown that a significant part of this variation may be due to changing meteorological conditions alone.

The results for the dust deposition rates averaged over the stations given in Table 42 are shown in Fig. 30 (NSW State Pollution Control Commission, Annual Report 1980d). The SPCC considers the level of 4 g/m^2/month as the level at which complaints may be expected and as the threshold level of dust pollution from coal mining activity in the Upper Hunter Region for which compensation may be possible. On that basis the dust levels in Newcastle are high. However, it is clear from Fig. 30 that dust deposition levels have decreased markedly since 1959 and the continuing downward trend is encouraging.

The data collected by the SPCC for suspended matter and ozone as well as the average acid gas data for seven stations available since 1975 are shown in Figs. 31 and 32. The average levels for each year are shown in Fig. 31 and the average maximum levels for each year are shown in Fig. 32. The seven stations used to obtain the average acid gas and suspended matter levels are shown in Table 42. Only one station (Adamstown) collects the ozone data shown in Figs. 31 and 32.

As indicated in Table 43 the acid gas and suspended matter standards should be considered together. It is clear from Fig. 31 that the WHO annual mean standard of 60 μgm^{-3} for acid gas concentrations is not violated for the 1975–81 period although the results for only three stations in Fig. 28 for 1958–82 indicate there have been periods when this standard is violated. It appears that the 1982 levels may also violate this standard but the accuracy of these results has been queried and we discuss this in more detail later on. However, even if the acid gas annual mean standard is violated the suspended matter results in Fig. 31 are well below the adopted annual mean guideline of 40 μgm^{-3} so that the combined acid gas and suspended matter results indicate little cause for concern at present.

The maximum acid gas levels shown in Fig. 32 show a recent marked increase exceeding the WHO standard for maximum 24 hour acid gas values of 200 μgm^{-3}. It is difficult to compare the recent acid gas levels directly with SO_2 standards since work in 1983 (Bridgman 1983) indicates that the acid gas data may contain the effect of substantial components of other gases (such as oxides of nitrogen). Therefore the WHO standard will be used throughout as this standard refers specifically to acid gas data collected in the way chosen in Newcastle. The

TABLE 42 Newcastle monitoring stations

Station		Air pollutant
Station	Suspended matter micrograms per cubic metre at 0 Degree C 24 hour sample	Acid gases expressed as sulphur dioxide micrograms per cubic metre at 0 degree C 24 hour sample
Boolaroo	Monthly average	Monthly average
Ambulance Station	standard deviation	standard deviation
Main Road	max. 24 hour average	max. 24 hour average
Kotara*	Monthly average	Monthly average
Seaview Street	standard deviation	standard deviation
	max. 24 hour average	max. 24 hour average
Lambton*	Monthly average	Monthly average
Elder Street	standard deviation	standard deviation
	max. 24 hour average	max. 24 hour average
Mayfield East*	Monthly average	Monthly average
Mounter Street	standard deviation	standard deviation
	max. 24 hour average	max. 24 hour average
Newcastle*	Monthly average	Monthly average
City Hall	standard deviation	standard deviation
King Street	max. 24 hour average	max. 24 hour average
Newcastle*	Monthly average	Monthly average
Watt Street	standard deviation	standard deviation
	max. 24 hour average	max. 24 hour average
North Stockton	Monthly average	Monthly average
Fullerton Street	standard deviation	standard deviation
	max. 24 hour average	max. 24 hour average
Waratah*	Monthly average	Monthly average
Turton Road	standard deviation	standard deviation
	max. 24 hour average	max. 24 hour average

* Newcastle City Council operated

WHO standard for acid gases of 200 μgm^{-3} was clearly violated in 1981. There has been some doubt about the 1981 results but it is shown later that the estimate given in Fig. 32 is reasonable.

The standard adopted for total suspended particulates for 24 hour maxima is 260 $\mu g/m^3$ but only one station (Boolaroo) in the outer suburbs monitors TSP. The TSP results at Boolaroo indicate that the TSP geometric mean standard adopted of 90 $\mu g/m^3$ may be in danger of being violated but the Boolaroo station is at the northern end of Lake Macquarie and, given the suspended matter results, it is doubtful if these results are representative of the Newcastle area but rather of factories at Boolaroo. The WHO standard for suspended matter of 120 $\mu g/m^3$ for 24 hour maxima is well above the data shown in Fig. 32.

TABLE 42 (Continued)

Station	Air pollutant
Adamstown Fletcher Street	Ozone parts per hundred million one hour average % daily one hour maxima —monthly average —standard deviation —max. one hour average NHMRC one hour goal —% time exceeded —no. days exceeded
Stockton Fullerton Street	Fluoride (gaseous and particulate) micrograms per cubic metre at 0 degree C weekly sample
Fern Bay Braid Street	Fluoride (gaseous and particulate) micrograms per cubic metre at 0 degree C weekly sample
Boolaroo Cnr. Lakeview & First Streets	TSP 24 hr sample over 6 day cycle (as lead, copper, iron) cadmium 24 hr sample over 6 day cycle
Monitoring Site*	Dust deposition rates** grams per square metre per month one month sampling period
Broadmeadow	65 Broadmeadow Road
Carrington	Bourke Street
Carrington	Public Works Department
Carrington	10 Fitzroy Street
Hexham	Old Maitland Road
Kooragang Island	No 2
Kooragang Island	No 1
Kotara	Woodlands Avenue
Mayfield	Ingall Street
Mayfield East	Walsh Street
Mayfield West	Maitland Road
Newcastle	City Hall
Newcastle	Scott & Market Streets
Rankin Park	Morton Parade
Stockton	Fullerton Street
Stockton	Pembroke Street
Tighes Hill	27 Kings Road
Wallsend	Richardson Street
Waratah	Lorna Street

* Newcastle City Council operated

** Expressed as combustible matter, ash, and insoluble solids.

Thus it would seem that, although the acid gas levels appear high, the particulate levels are low enough to avoid health problems. The dust deposition levels indicate that the aesthetic effects due to high dustfall levels may lead to complaints but the trend in dustfall levels does appear to be downward.

The TSP data collected by the SPCC at Boolaroo have been analysed for concentrations of lead. It is very likely that the adopted standard for 90-day averages of 1.5 $\mu g/m^3$ for lead has been violated as annual means of lead concentrations recorded between 1975 and 1981 range from 2.2 to 4.0 $\mu g/m^3$ (NSW SPCC Annual and Quarterly Air Quality Monitoring Reports, 1975–81). Such levels indicate that lead may be a problem due to nearby factory emissions but the contribution from motor vehicles is unclear.

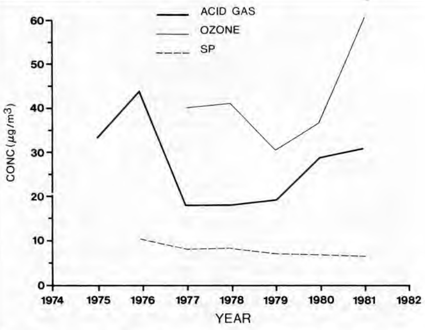


FIGURE 31 **The mean concentrations at seven stations for acid gas and suspended matter 24 hour readings, and for 1 hour ozone levels at Adamstown monitor**

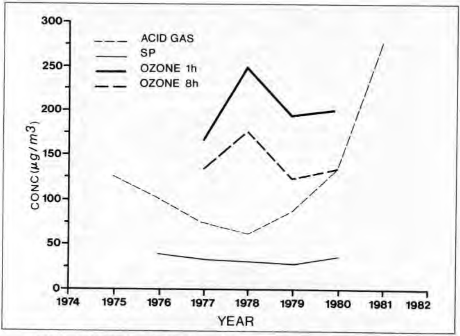


FIGURE 32 As in Fig. 31 for maximum 24 hour readings of acid gas and suspended matter, 1 hour ozone readings and 8 hour ozone readings

The ozone data from Adamstown station shown in Fig. 32 indicate that the adopted NHMRC standard of 12 pphm (or approximately 235 $\mu g/m^3$ at 25 °C) for 1 hour ozone levels is rarely exceeded although the WHO 1 hour (6 pphm) and 8 hour (3 pphm or 60 $\mu g/m^3$) standards often are violated. The new Australian Design Rules (ADR) for motor vehicles which begin taking effect from 1986 on new model cars may alleviate the smog problem. However, in an industrial city such as Newcastle, where the contribution to NO_x levels from industry should be substantial, it would be desirable to estimate the relative contribution to the precursor gases of photochemical smog (NO_x and hydrocarbons) from industry and motor cars in order to estimate the effectiveness of the new ADR rules in reducing smog levels in Newcastle. Carbon monoxide data are not available for Newcastle and the monitoring of this pollutant may indicate whether serious air pollution occurs due to motor vehicles. The monitoring of nitrogen dioxide would also be useful in determining the causes of the ozone problem and whether this gas by itself causes an air pollution problem.

TABLE 43 Air quality standards used as guidelines by the SPCC (Ref: SPCC Quarterly Air Quality Monitoring Report, Vol 8, No. 2, 1982)

Pollutant	Standard	Agency
*Acid gases (24 hour)	60 $\mu g/m^3$ (Annual mean)	WHO
	200 $\mu g/m^3$ (24 hour maximum)$^+$	
*Suspended matter (24 hour)	40 $\mu g/m^3$ (Annual mean)	WHO
	120 $\mu g/m^3$ (24 hour maximum)$^+$	
Total suspended particulate	90 $\mu g/m^3$ (Annual geometric mean)	NHMRC
	260 $\mu g/m^3$ (24 hour maximum)	USEPA
Lead	1.5 $\mu g/m^3$ (90 day average)	NHMRC/USEPA
Carbon monoxide	35 ppm (1 hour maximum)	WHO/USEPA
Non-methane hydrocarbons	24 pphm (3 hours maximum)	USEPA
Nitrogen dioxide	17 pphm (1 hour maximum)	NHMRC
	5 pphm (Annual arithmetic mean)	USEPA
Ozone	12 pphm (1 hour maximum)	NHMRC/USEPA
Sulphur dioxide	14 pphm (24 hour maximum)	USEPA
	2 pphm (Annual arithmetic mean)	NHMRC

* Acid gases and suspended matter considered in conjunction with one another. Here suspended matter refers to particle sizes in the range 0.1–12 μm and total suspended particulates to particle sizes in the range 0.1–100 μm.

$^+$ Not to be exceeded more than 2 per cent of time per year, and in that 2 per cent not on consecutive days.

Pollutant	Units	Convert to	Multiply by
Carbon monoxide	ppm	mg/m^3 (0 °C)	1.25
		mg/m^3 (25 °C)	1.15
Lead	$\mu g/m^3$ (0 °C)	$\mu g/m^3$ (25 °C)	0.92
Non-methane hydrocarbons	ppm	mg/m^3 (0 °C)	0.71
		mg/m^3 (25 °C)	0.65
Nitric oxide (NO)	pphm	$\mu g/m^3$ (0 °C)	13.4
		$\mu g/m^3$ (25 °C)	12.3
Nitrogen dioxide (NO_2)	pphm	$\mu g/m^3$ (0 °C)	20.5
Nitrogen oxides (NO_x)		$\mu g/m^3$ (25 °C)	18.8
Ozone	pphm	$\mu g/m^3$ (0 °C)	21.4
		$\mu g/m^3$ (25 °C)	19.6
Sulphur dioxide	pphm	$\mu g/m^3$ (0 °C)	28.6
		$\mu g/m^3$ (25 °C)	26.2

The fluoride levels are monitored at Fern Bay and Stockton by the SPCC and have been compared with the levels at Kurri Kurri where the Alcan aluminium smelter is situated. The health standards adopted by other countries refer to 24 hour average values (for example see Stern

1977) and range from 1.3 to 30 μgm^{-3} as fluoride. The results for Newcastle are based on weekly averages and if only health effects are considered the reported annual averages in Newcastle of less than 0.8 μgm^{-3} indicate no problems due to fluoride emissions. However, the effect of the new aluminium smelter at Tomago needs to be monitored and this is discussed further in Chapter 6.

The results shown in Figs. 28 to 32 show that fluctuations of air pollution concentrations with time may be substantial. The most extensive data sets in our possession are the acid gas data sets so the fluctuations in acid gas are studied in detail from now on in this chapter. The primary purpose of this study is to ascertain how much of the fluctuations is due to meteorological change. Only when this 'natural' effect can be estimated will it be possible to estimate the effectiveness of the emission controls currently operating and then to hypothesise worst case scenarios associated with future industrial development in the region.

The effect of meteorological change on air pollution levels

The results shown in the early part of this chapter indicate that the acid gas levels changed significantly for each station during 1959–82. In fact extremely high levels toward the end of 1981 and at the beginning of 1982 have led to the suggestion that the chemical analysis used in estimating acid gas levels may be in error. Certainly it is not clear why levels should increase from 1980 to 1982 considering that the downturn in industry in the area should have led to a reduction in emissions rather than an increase. No emission data have been made available to us so instead an estimate is made here of how much of the variation in acid gas levels is due to meteorological change alone. This analysis is limited by the meteorological monitoring network since no meteorological data have been collected at the acid gas monitoring sites. We have chosen to use the data base from the meteorological station at the Williamtown air force base approximately 20 km NNE of Newcastle and near the coast. It has the most extensive and accessible records.

The data set

The first acid gas data set considered here consists of ten years of observations of daily levels measured by the Health Division of the Newcastle City Council at the Watt St, Mounter St and City Hall monitoring stations for the period January 1972 to December 1981. The readings are taken daily at 9.00 am for five days per week. Each reading is an average of the previous 24 hours. After consultation with the Health Division and the New South Wales State Pollution Control Commission, three days of the Watt St data in late 1981 have been deleted. The subsequent conclusions are in no way affected by this deletion but this exclusion is discussed later.

The meteorological data consist of ten minute average wind speed data recorded every three hours at the Williamtown Airport weather station. The wind speeds have been recorded on a Dines anemometer. This data set has been used to compute daily wind speed averages over the 9.00 am to 9.00 am periods for which the acid gas levels have been recorded.

Model for predicting maximum acid gas levels

The CRES air quality model for urban air pollution developed by Simpson *et al* (1983) has been used here to estimate the effect of meteorological change on maximum acid gas levels. This model is briefly described in Appendix VII. Simpson and Jakeman (1984) have applied the model on Watt St and Mounter St data using Williamtown wind speed data and achieved satisfactory results. However the model predictions of City Hall data were sometimes erratic though generally good.

The CRES model has the capacity to incorporate the effect of the changing statistics of wind speed data on air pollution levels. The model estimates a factor, K, which is the product of emission strength and atmospheric stability. Simpson *et al* (1983) link this factor to the parameters of the model developed by Gifford and Hanna (1973) at the Atmospheric Turbulence and Diffusion Laboratory, Oak Ridge, Tennessee, USA (see Appendix VI for details of the model). The ATDL model, in its simplest form (eg Hanna 1971), relates long-term averages of the air pollution concentration, χ, and wind speed, u, by the equation

$$\chi = CQ/u \qquad (5.1)$$

where Q is the area source strength ($\mu g/m^2/s$) and C is a constant theoretically dependent an atmospheric stability. Although theoretically C may vary from 50 to 600 depending on atmospheric stability, Hanna (1971) has found in practice that it varies little with atmospheric stability. For SO_x (oxides of sulphur) data Gifford and Hanna have found that $C \sim 50$ for ~ 10 km square grids in urban areas. Hanna (1971) has also shown that equation (5.1) yields reasonable results for SO_x data even given the source specific and wind direction sensitive nature of SO_x emissions. Given the data of Saw (1983) for 1979–80 SO_2 emissions in Newcastle, it is possible to obtain an estimate of $Q \sim 2.0\ \mu g/m^2/s$ for a 10 km square grid in Newcastle City. Simpson and Jakeman (1984) obtain a K-value of about 60–90 in 1979–80, so that C ∿ 30–45, a comparable value to that of Gifford and Hanna. In fact the ATDL C values are derived from the means of the other variables in equation (5.1) while here the K factor is derived from the medians. The corresponding K factor needs to be increased 30–40 per cent, leading to a C-value of about 50.

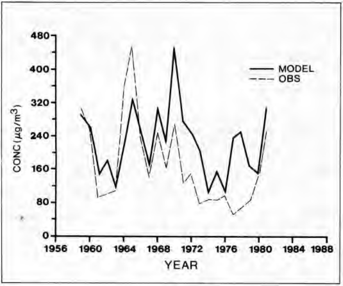


FIGURE 33 Comparison of observed and predicted maximum acid gas levels at Watt St station for 1959–81

The predicted maxima are compared with observations in Figs. 33, 34 and 35 for Watt St, Mounter St and City Hall, respectively for 1959 to 1981. It is clear that the model predictions of the maxima are to within a factor of 2 for the first 2 stations but not as good for City Hall. The variation of K is shown in Fig. 36 for these 3 stations and the combined data set of the 3 stations, the latter values probably yielding a better estimate of the average trends given the large fluctuations in K. It is interesting to note in Fig. 36 that there is agreement between the relative decrease in emissions after 1971 (indicated by the decrease in K-values) and the historical evidence put forward by Moore (1982) of the introduction of low sulphur coal for combustion at that time.

It is also noticeable that some of the high maxima recorded in 1981 (eg at Watt St) do not need to be explained by an increase in emissions. For instance, the maximum acid gas reading in Watt St in 1981 was about double that in 1980 although the K-values are about the same. This is just one example of how a change in wind statistics (or regime) from one year to the next may substantially change the maximum levels recorded. In fact the results in Figs. 33 to 35 show that maximum levels may change by a factor of 4 to 6, and about half of this change is directly due to the change in wind regime. The other changes are due to changes in the K-value which may be partly dependent on meteorological change but should mainly reflect changes in emissions.

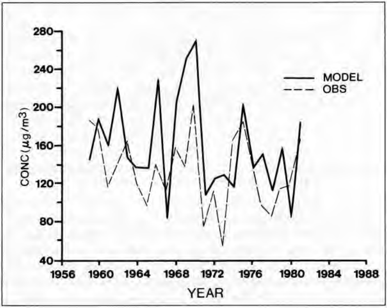


FIGURE 34 As in Fig. 33 for Mounter St station

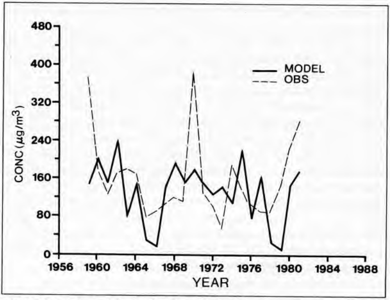


FIGURE 35 As in Fig. 34 for City Hall station

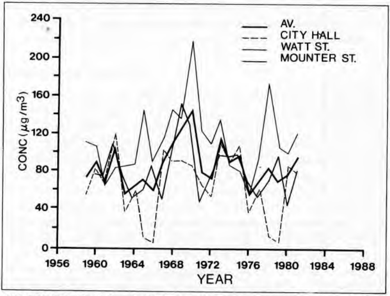


FIGURE 36 Variation in K-factors for each of Watt St, Mounter St and City Hall acid gas data sets as well as for the average for all three sites for 1959–81

Using a statistical distribution to obtain the estimate of the observed maximum also is a good way of handling 'outliers' or spurious data. An example of this is shown in Fig. 37 where 1981 acid gas observations are plotted on a lognormal scale using all the available data including the suspect data left out by the SPCC. The reading at over 500 μgm^{-3} is an obvious outlier and is ignored by using the statistical fit to the data. Using a 2-parameter lognormal distribution to represent the observations in Fig. 37 yields an expected maximum of 260 μgm^{-3} The four days of data left out by the SPCC in its 1981 quarterly report for Oct–Dec were 250, 293, 559 and 246 μgm^{-3} leaving the highest value reported as 188 μgm^{-3}. Clearly the SPCC may have been conservative in their approach and this is one example of how the use of the statistical distribution yields a more objective basis for recognising outliers. One of the reasons for ignoring the values of over 200 μgm^{-3} may have been that since the emissions should have reduced in 1981 the increase in acid gas levels appeared suspect. In fact this increase in acid gas levels can be explained by considering the meteorological change alone.

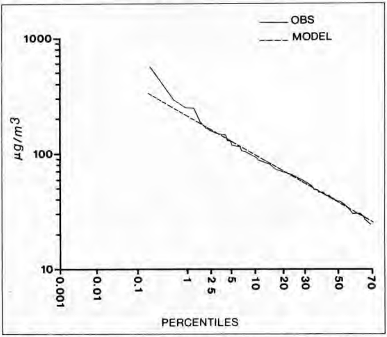


FIGURE 37 **The cumulative frequency distribution for Watt St acid gas data in 1981 comparing observations with the lognormal statistical fit**

There has also been some question about the validity of the 1982 acid gas results recorded in Newcastle. We have compared the cumulative frequency distribution of the observations from Watt St station and the model used to fit them using the first 10 months of data for 1982. There was a reasonable fit and both the estimated maximum and the measured maximum results yield a maximum concentration of approximately 400 μgm^{-3}. The model identifies a K value of over 200, more than twice as high as for 1972 to 1981. It is unlikely that emissions increased that dramatically from 1981 to 1982. Given the economic downturn it is likely that they decreased so the change must be due either to a substantial change in atmospheric conditions or the results are spurious. Before advocating the latter it would be important to understand more clearly how atmospheric conditions might drastically affect the acid gas levels. The work of Dixon (1984) indicates that inversion effects and long range transport from outside Newcastle may be important. The latter effect especially would lead to inaccuracies given the limitations of the model used. However, recent work by Bridgman (1983) does indicate that recent acid gas records may be in error, while Dixon (1984) has shown that the acid gas data sets have a consistency across monitoring sites which supports their acceptability at least as a relative indication of acid gas pollution in Newcastle. Nevertheless the K-factors obtained here for 1979–80 agree with the work of Gifford and Hanna (1973) who have applied the ATDL model to many different urban situations.

Worst case scenarios

The results in the previous section allow the formulation of worst case scenarios for Newcastle based on 30 years of wind speed data available from Williamtown. The CRES model may be used to predict the expected fluctuations in maximum acid gas levels due to meteorological change (eg see Appendix VII). The factor, $(\beta)^{2.94}/\alpha$, indicates the effect of changes in wind speed statistics on maximum 24 hour average acid gas levels, where α and β are the geometric mean and geometric standard deviation, respectively, of the lognormal statistical distribution representing the wind speed data. The variation of this factor for Williamtown wind speed data is shown in Fig. 38. It may be seen from Fig. 38 that the years 1959, 1960 and 1966 appear to represent the most extreme fluctuations in meteorological behaviour likely to lead to highest pollution episodes in the period 1951–81, and the years 1957 and 1974 the lowest. Using the CRES model it is possible to predict the maxima expected in such meteorological conditions under various scenarios of emissions. It is also possible to estimate the number of violations of various standards. Here violations are considered for the WHO acid gas standards of an annual mean of 60 $\mu g/m^3$ and a desirable maximum 24 hour average of 200 $\mu g/m^3$.

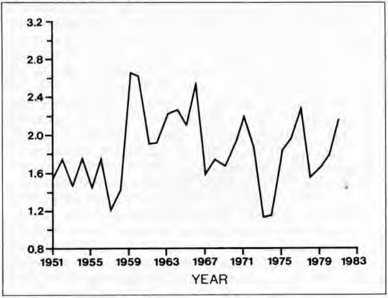


FIGURE 38 Variation of the meteorological factor for the years 1951–81

Table 44 shows the results of using emission scenarios based on the present average for 1972–81 for the 3 sites considered in the last section and staged increases of these emissions. Using the average CRES model parameter K and the suggested corresponding ATDL parameter for SO_2 data then the average emission load at present in the Newcastle area is 63 tonne/m^2/year or 6300 tonne/year for a 10 km square grid in the central Newcastle area. The data of Saw (1983) for the central Newcastle area which are based upon estimates of fuel inputs to industrial processes suggest a total for SO_2 emissions of order 6000–7000 tonne/year for Newcastle industry, so the adopted value is reasonable. It is clear from Table 44 that a doubling in present acid gas emissions may lead to significant violations of the WHO 24 hour maximum acid gas levels as well as violating the WHO annual mean standard of 60 $\mu g/m^3$. It is notable that such violations could occur two years in succession and 3 out of 8 years, given the data in Table 44. It is also clear that there will

TABLE 44 Worst case scenarios with present and projected changes in acid gas emissions

		Maximum concentration χ_m ($\mu g/m^3$) and percentage, P, of violations of WHO standard of 200 $\mu g/m^3$**				
		High pollution years			Low pollution years	
Emission load		1959	1960	1966	1957	1974
Present*	χ_m	187	183	180	84	81
25% increase	χ_m	234	229	225	105	101
	P	0.7	0.6	0.6	0	0
50% increase	χ_m	281	275	270	126	122
	P	1.5	1.4	1.4	0	0
100% increase	χ_m	374	366	360	168	162
	P	4.6	4.2	4.7	0	0
		Mean concentrations ($\mu g/m^3$) (WHO standard = 60 $\mu g/m^3$)				
Present		34	33	36	22	22
25% increase		43	41	45	28	28
50% increase		51	50	54	33	33
100% increase		68	66	72	44	44

* Present emission load 6300 tonne/year (average 1972–81).

** Not to be exceeded more than 2% of the time, and not on consecutive days within that 2%.

be years when neither standard is in any danger of being violated even if the emissions are more than doubled.

Of course the acid gas standards should be considered in conjunction with suspended matter data. There are no detailed records of suspended matter available except for the published annual means and maximum 24 hour levels since 1975. Nevertheless Simpson *et al* (1983) have shown that the CRES model is applicable to TSP data in Brisbane and carbon monoxide data in Canberra, and the CRES model has been successfully applied to acid gas data in Newcastle at which suspended matter data are also recorded. Therefore it is not impractical to apply the CRES model to the suspended matter. The model predictions for suspended matter 24 hour maxima from 1976–81 for Mounter St, Watt St, and City Hall data are compared with the observed maxima in Table 45 (we had only the means available before 1975, not the maxima).

Certainly the results are encouraging. Consequently the model has been used to estimate a mean suspended matter emission rate using the mean CRES model parameter (K = 21) and the ATDL parameter for TSP. The ATDL parameter for TSP should be the same for suspended matter as it is only a function of meteorological conditions and the spatial nature of the source strengths, both of which should be similar for suspended matter and TSP emissions. As mentioned previously the medians of the data are used while the ATDL parameters refer to the means leading to an adjustment of 60–70 per cent. The adopted ATDL value for C is C $\sim$ 225, which yields a value of $\sim$ 145 for comparison with our K-factor. This leads to an estimated mean emission for the 10 km square in Newcastle city for 1975–81 of approximately 500 tonnes/year of suspended matter. On the basis of fuel inputs and technological assumptions Saw (1983) estimates that the total particulate emission load in central Newcastle including dustfall in 1979–80 was over 4000 tonne/year. Without knowing the proportion of the particulates with diameters between 0.1 and 10–12 μm it is not possible to gauge the accuracy of the chosen emission factor but it does appear to be of the right order of magnitude.

TABLE 45 Comparison of predicted (χ_m) and observed (χ_o) 24-hour average suspended matter data (μg/m^3)

	Station					
	Mounter St		Watt St		City Hall	
	χ_o	χ_m	χ_o	χ_m	χ_o	χ_m
1976	39	47	44	32	33	22
1977	38	59	47	44	33	39
1978	37	38	26	27	25	30
1979	21	21	40	28	36	28
1980	57	37	44	33	39	33
1981	39	35	36	35	37	31

Given this estimate it is then possible to repeat the analysis that was carried out for acid gas to consider worst case scenarios from the meteorological regimes monitored at Williamtown from 1951–81. The results are shown in Table 46. It is clear that suspended matter levels would have to increase fourfold in order for the WHO annual mean standard of 40 μg/m^3 to be violated and also for the occurrence of a significant number of violations of the WHO maximum 24-hour average value of 120 μg/m^3.

Therefore in order for serious health problems associated with the combined effect of acid gas and suspended matter to occur it would appear that the acid gas emissions need to double and the suspended matter emissions need to increase four-fold. However, it is important to note that the estimate of acid gas emissions may be lower than the actual (Saw 1983). Also the estimate of K in the model is probably only accurate to within a factor of 2. Therefore it probably would be advisable not to allow acid gas emissions to rise any further in the Newcastle area. The estimate of suspended matter emissions also may be an underestimate. Nevertheless it would appear that suspended particulate emissions may be allowed to increase slightly without due cause for concern given the low levels recorded. Of course as mentioned previously the dustfall levels are high so it would appear desirable to concentrate particulate control on the larger particle sizes.

Conclusions

The results in this chapter clearly indicate that, in estimating air quality levels, as extensive a data base as possible is necessary. Chapter 4 considered SO_2 levels in the Upper Hunter Region due to Liddell power station for a data base spanning less than two years in 1980 and 1981. By comparing the meteorology of those two years with other years it was suggested that significant increases may occur due to changing meteorology. In this chapter the magnitude of the change possible becomes quite clear. Due to different meteorological factors the maximum acid gas levels may also change by almost a factor of 3 in one climatological period.

It is acknowledged that the air pollution problems in Newcastle and the Upper Hunter Region will be affected in different ways by meteorological change. In Newcastle there is a variety of low level releases sensitive to meteorological circulation patterns such as those suggested by Dixon (1984). In the Upper Hunter Region the high level releases from a few elevated sources were considered to be sensitive to the number and heights of inversions. The work in this chapter underlines the danger of using a short meteorological data base to estimate an air quality impact.

There appear to be air quality problems in the Newcastle area due to high acid gas and ozone levels and dustfall. There is also a lead problem at Boolaroo. The ozone problem probably will be alleviated by the use of unleaded petrol which will, with the use of catalytic converters on vehicles, reduce emissions of the precursor gases for the formation of photochemical smog. It is likely, however, that the lead problem at Boolaroo is due more to industrial rather than motor vehicle pollution.

It is suggested that monitoring of carbon monoxide and nitrogen dioxide should be undertaken to examine both the contribution to air pollutants from motor vehicle emissions and the contribution by industry. At present acid gas levels may be quite high but the suspended matter levels are low enough to prevent a serious health problem due to the combined effects of acid gas and particulates. It would appear that any significant increase in acid gas emissions above the present could lead to acid gas levels above the WHO standards. However, a substantial increase in suspended particulate emissions (at least a doubling of present emissions) would be needed to violate the WHO suspended matter standards. Since the effects of acid gas and suspended matter need to be considered together there seems little cause for concern at present about the effect of these pollutants in Newcastle. However, the dustfall levels are high enough for a loss of social amenity to be

TABLE 46 Worst case scenarios with present and projected changes in suspended matter emissions

	Mean concentration ($\mu g/m^3$) (WHO standard = 40 $\mu g/m^3$)				
	High pollution years			Low pollution years	
Emission load	1959	1960	1966	1957	1974
Present	10	10	11	7	7
Doubling	20	20	22	14	14
Tripling	30	30	33	21	21
Four times more	40	40	44	28	28

		Maximum 24 hour concentration ($\mu g/m^3$), χ_m, and percentage (P) of violations of WHO standard = 120 $\mu g/m^3$*				
		High pollution years			Low pollution years	
Emission load		1959	1960	1966	1957	1974
Present	χ_{max}	56	55	54	25	24
Doubling	χ_{max}	112	110	108	50	48
Tripling	χ_{max}	168	165	162	75	72
	P (%)	1.6	1.4	1.4	0	0
Four times more	χ_{max}	224	220	216	100	96
	P (%)	4.7	4.2	4.8	0	0

* 98% of observations should fall below this standard

occurring although the trend is downward. It would appear then that dust control should concentrate on controlling the larger particle sizes.

Given the sensitivity of air quality monitoring results to meteorological change it is recommended that monitoring stations be established which would continuously record all the major pollutants (SO_2, ozone, TSP and NO_x) as well as continuously monitor wind speed and wind direction. It is acknowledged that the work here does not estimate the effect of long range transport of SO_2 from sources outside Newcastle. A detailed study is required to assess such impacts.

6

Major industrial sources in the Lower Hunter Region

Introduction

In this chapter particular attention is paid to the major industrial sources in the Lower Hunter Region outside of Newcastle which could be expected to contribute significantly to air pollution levels. The sources considered are the power stations south of Newcastle, the Alcan aluminium smelter at Kurri Kurri, and the new aluminium smelter which commenced operation at Tomago in September 1983. The air pollutants of concern are fluoride and sulphur dioxide emissions from the aluminium smelters and sulphur dioxide emissions from the power stations. The construction of the proposed Lochinvar aluminium smelter has not proceeded because of economic circumstances but the possible impacts, if such a proposal were again considered, are also discussed.

It is made clear here that the data base available is somewhat scant and recommendations are made to improve on this. It would appear from the results presented, however, that the fluoride levels give cause for caution. The sulphur dioxide emissions from both the power stations and the aluminium smelters may also exacerbate the acid gas problem in Newcastle. This chapter stresses that both future sulphur dioxide producing development in the Lake Macquarie area and future acid gas producing development in the Newcastle, Maitland or Cessnock areas be treated with caution.

The industrial sources

All power stations in the sub-region are coal-fired and operated by the NSW Electricity Commission south of Newcastle. They are Wangi A (150 MW), Wangi B (180 MW), Vales Point A (875 MW), Vales Point B (1320 MW), Munmorah (1400 MW), and Eraring (660 MW) (see NSW Electricity Commission, Annual Report 1982). The locations of these stations are shown in Fig. 39. The Eraring power station will eventually have a capacity of 2640 MW. Thus the potential total power output for all of these stations is 6565 MW, all base load requirements. A rough comparison of the SO_2 emissions due to these power stations with other sources in the region is given in Table 47.

TABLE 47 Rough estimates of SO_2 emissions from major sources in the Hunter Region

Source	Annual SO_2 Emissions (kg x 10^6)	
Electricity Commission of NSW Power Stations		
Wangi	1.5 (180 MW)	Calculated from estimated coal use in 1982 multiplied by 0.45%
Munmorah	11.0 (1400 MW)	
Vales Point	14.0 (1320 MW)	
Liddell	20.0 (2000 MW)	
Eraring	27.0 (2640 MW)	
Bayswater	26.0 (1320 MW by 1986)	by 0.7%S
Subtotal	99.5 (8860 MW)	
Tomago Aluminium Smelter	21.3	Based on EIS estimate
Kurri Kurri Aluminium Smelter	13.1	Based on EIS estimate
Broken Hill Pty Ltd	2.9	Coal burning processes 0.26%S
Fertiliser plants	4.2	
TOTAL	141.0 x 10^6 kg/yr	

Assumes full production in all cases

Source: Rothwell *et al* (1984).

The location of the aluminium smelters at Kurri Kurri and Tomago is also shown in Fig. 39, and the projected SO_2 emissions due to Tomago and Kurri Kurri (including the recent extension) are given in Table 47. It is clear from Table 47 that the SO_2 emissions from the power stations in the Lower and Upper Hunter contribute most to the total SO_2 load. However, the SO_2 emissions from the aluminium smelters are also significant compared to those of the major industries in Newcastle. Therefore the SO_2 levels are first studied, and then the fluoride levels near the aluminium smelters.

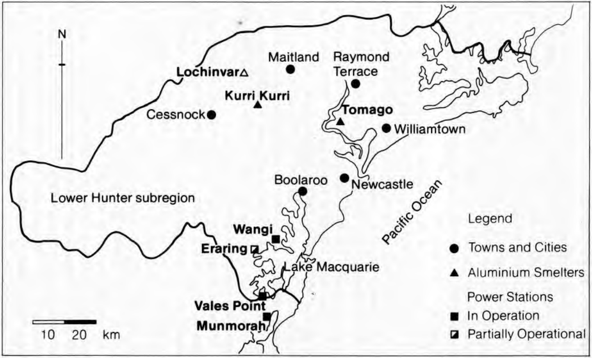


FIGURE 39 The location of power stations and aluminium smelters in the Lower Hunter Region

Sulphur dioxide levels

The SO_2 emission estimates referred to in the previous section suggest that the power stations to the south of Newcastle significantly add to the total SO_2 emissions in the Hunter Region. The 'control' strategy adopted to ensure that ground level concentrations of SO_2 do not exceed guidelines is the same as for the power stations in the Upper Hunter Region, namely use of the 'tall-stack' approach. This approach requires the construction of tall stacks with buoyant plumes which allow the dilution of SO_2 concentrations to acceptable levels by the time that the plumes reach ground level.

From Chapter 4 it is evident that the maximum levels to be expected due to each power station in a given location are not usually additive at a particular time. This is also true in the Lower Hunter Region where the stations are well spaced. So it is the effect of each power station which needs to be considered in turn when high ambient pollution levels are being investigated. The NSW Electricity Commission has supplied SO_2 data monitored at a number of sites in the area. These monitoring sites are all close to the power stations in question and so cannot be expected to record the maximum levels possible due to each power station. However, these data do show the fluctuations that can occur from year to year. The time periods and the completeness of each data set are shown in Table 48. The number of times half hour average SO_2 levels above 5 pphm were recorded is shown in Table 49.

The levels recorded are quite low compared to the short term SO_2 standards considered in Chapter 4. The lowest hourly standard (Japan) considered is 10 pphm and the only half hourly standard considered (W. Germany) is 30 pphm. However, work in Chapter 4 indicates that the monitoring network for point sources needs to be both carefully chosen and extensive. Certainly any assessment of impact for point sources needs to be accompanied by a modelling exercise.

No models were used in our study. Instead, the results of the modelling exercise of James *et al* (1983) for the Hunter Region are considered. The James *et al* model estimates annual averages for SO_2 levels to be in the range 4-6 $\mu g/m^3$ (approximately 0.15–0.23 pphm). These are estimates resulting for emissions from both present and proposed developments in the region. The model predicts maximum 3 hour SO_2 ground level concentrations of around 400 $\mu g/m^3$ (approximately 15 pphm). This level is likely to occur when the Eraring power station is running at full capacity. They note that although this estimated maximum SO_2 level is below the USEPA 3 hour standard (50 pphm or 1300 $\mu g/m^3$) it violates the West German 3 hour standard of 270 $\mu g/m^3$ and is close to standards set in some American states such as Delaware (450 $\mu g/m^3$). They also note that 3 hour levels in excess of 200 $\mu g/m^3$ (7.7 pphm) would not be exceeded more than 20 per cent of the time in the Lake Macquarie area. These modelling results are consistent with the conclusions that present SO_2 emissions do not cause serious problems but the proposed full operation of Eraring may do so. However, the conclusions in Chapter 4 suggest that the modelling results of James *et al* (1983) and the monitoring results shown in Table 50 need to be treated with some caution.

TABLE 48 Data sets for power stations south of Newcastle—Percentage of data available and extent of each

0–30% / 30–70% X 70–100%

	Months												
Station/Year	J	F	M	A	M	J	J	A	S	O	N	D	Notes*
Eraring/81			X	X	X	X	X	X		/	X	X	78% data
Vales Pt/80	X	X	X	X	/	/	X		X	X	X	X	73% data
Vales Pt/81	X	/	/		X			X	X	X			
Munmorah/74							X	X	X	X	X	X	
Munmorah/75			/	/	X	X	X	X	X	X	/	X	
Munmorah/76	/	X	X	/	X	X	X	X	/	X	X	X	
Munmorah/77	/	/	/	X	/					/	X	X	
Munmorah/78	X	X			X			X		X	/		62% data
Munmorah/79	X	/	X	X	X	X	X	/	X	/	/	/	
Munmorah/80							X	X	X	X	X	X	
Munmorah/81	X	X	/	X	X	X	X	X	X	X			

* % data is for all months for which some data exists.

It was argued in Chapter 4 (where the current impact of Liddell power station was considered) that the monitoring results and the models used were critically dependent on the effects of atmospheric temperature inversions. This was also true in considering the future impact of Bayswater power station. For instance, it was important that the length of the monitoring data included periods representative of serious inversion influences. The work of Dixon (1984), shown in Tables 24 and 25, indicated that 1980 and 1981 were not years where a large number of low level inversions occurred. Thus the Vales Point and Eraring SO_2

data covering the years 1980–81 and 1981 respectively, may not be reflective of possible fluctuations. The Munmorah data set from 1974–81 shown in Table 50 indicates fluctuating levels from 0–15 pphm but there is no clear dependence of these fluctuations on the behaviour of the inversions at Williamtown as reported by Dixon (1984).

TABLE 49 Number of SO_2 measurements (½ hour average) above 5 pphm for power stations

	Months*											
Station/Year	J	F	M	A	M	J	J	A	S	O	N	D
Eraring/81	-	-	-	-	-	-	-	-	-	-	-	-
Vales Pt/80	-	-	-	-	-	-	-	-	-	-	-	-
Vales Pt/81	-	-	-	-	-	-	-	-	-	-	-	-
Munmorah/74	-	-	-	-	-	-	-	-	15	-	25	-
Munmorah/75	-	-	-	-	2	-	2	1	-	-	-	-
Munmorah/76	-	-	-	-	-	-	-	-	-	-	-	1
Munmorah/77	3	-	-	-	-	-	-	-	-	-	1	4
Munmorah/78	-	-	-	-	-	-	-	-	-	-	-	-
Munmorah/79	-	-	-	-	-	-	-	-	-	-	-	-
Munmorah/80	-	-	-	-	-	-	-	-	-	-	2	-
Munmorah/81	-	-	-	-	-	-	-	-	-	-	-	-

* For all months with more than 30% data.

TABLE 50 Maximum SO_2 levels, in pphm, (½ hour averages) for power stations

	Months*											
Station/Year	J	F	M	A	M	J	J	A	S	O	N	D
Eraring/81	-	-	0	0	0	0	0	2	-	0	0	0
Vales Pt/80	2	3	3	3	2	0	0	-	2	3	2	2
Vales Pt/81	2	0	0	-	1	-	-	0	1	2	-	-
Munmorah/74	-	-	-	-	-	-	4	4	6	4	7	3
Munmorah/75	-	-	1	-	15	2	5	5	1	2	0	3
Munmorah/76	0	3	3	2	2	4	4	4	1	1	2	5
Munmorah/77	5	2	2	2	3	-	-	-	-	2	5	8
Munmorah/78	4	5	-	-	3	-	-	1	-	2	0	-
Munmorah/79	2	1	2	1	2	2	1	1	2	0	1	0
Munmorah/80	-	-	-	-	-	-	2	2	2	4	8	3
Munmorah/81	2	1	2	3	2	2	2	2	2	1	-	-

* For all months with more than 30% data.

The model used by James *et al* (1983) is the SCA (Smeared Concentration Approximation) model of Dennis (1978) which incorporates the Gausian plume point source modelling approach used in Chapter 4. As shown there, the model results are critically dependent on inversion effects which are not incorporated into the SCA model. Certainly the fluctuations in SO_2 maxima shown in Table 50 indicate the possible impact of meteorological fluctuations but it is unlikely that these monitors measure the maximum levels (as did the network in the Upper Hunter Region). It is then quite reasonable to agree with James *et al* that the extension of Eraring power station may lead to high maximum levels and add that it is not clear that even the USEPA 3 hour standard of 50 pphm would not be exceeded under trapping conditions (as discussed in Chapter 4).

The latter point is reinforced by the SCA model results of James *et al* for Bayswater and Liddell power stations. They estimate 300 $\mu g/m^3$ (11.5 pphm) as the maximum 3 hour SO_2 levels to be experienced, significantly less than our estimates in Chapter 4. Therefore the recommendations of the James *et al* report not to introduce any new industries producing SO_2 in the region around Lake Macquarie need to be treated with sympathy. However, monitoring exercises for SO_2, NO_x and particulates would help clarify the uncertainties and would need to be undertaken in the face of proposed development. Ideally, it is the combined effects of these three pollutants which should be considered.

The contribution to SO_2 levels from the aluminium smelters at Kurri Kurri and Tomago is less clear. The results in Chapter 5 suggest that acid gas levels in Newcastle are already at a level of some concern. The proximity of the Tomago smelter to Newcastle could exacerbate this problem given the emissions presented in Table 47. However, Newcastle City Council Health Division (Fullick 1984) reported that there had been no additional effect perceived by their acid gas monitors during the first few months that the Tomago smelter was in full operation. James *et al* (1983) also advise caution in allowing any new developments which would produce acid gases in the Newcastle region. They argue that if the Lochinvar aluminium smelter development had proceeded, then Maitland would also be reaching an upper limit to acid gas producing industry. The maximum 3 hour SO_2 levels near Kurri Kurri were estimated by them to be in excess of 200 $\mu g/m^3$ (7.7 pphm) so that any increase in industrial development in that area would affect Cessnock as well.

Quite clearly a more extensive data collection network is necessary to more accurately estimate future impacts in the area south of Newcastle.

Fluoride levels

Table 51 contains some relevant data for the effects of ambient fluoride levels. Health and material effects are not considered because the levels necessary for damage are far in excess of those necessary to kill sensitive vegetation. The daily human intake of fluoride inhaled from ambient air is only a few hundredths of a milligram which represents only a small fraction of the normal total fluoride intake (see Appendix I).

Animals, on the other hand, may additionally be exposed to fluoride from ingested fresh forage or hay, feed supplements and the water supply in areas where fluoride pollution is a problem. The damage thresholds for animals in Table 51 have been obtained from controlled experiments where a relationship has been assumed between forage concentration and ambient concentration (Suttie 1969). The damage thresholds specified for vegetation relate to injury defined as any measurable effect on the plant as a result of exposure.

The NSW State Pollution Control Commission (1980b) report on pollution control required for aluminium smelting suggests that plant species be graded as 'sensitive', 'intermediate', and 'resistant', to fluoride damage. Based on this grading the report indicates that visible damage is noticeable when foliar fluoride levels are about 50 μg/g for sensitive plants, more than 200 μg/g for intermediate plants, and greater than 500 μg/g for resistant plants. SPCC data from monitoring at Kurri Kurri show that minor damage occurs in sensitive plants when 3-month ambient atmospheric averages are above 0.5 $\mu g/m^3$ in agreement with overseas data. For grape leaves, the report notes that significant damage is expected to occur for fluoride concentrations of 25–30 μg/g. However, the SPCC notes that, over a ten year period of monitoring at Pokolbin near Cessnock, where the major vineyards of the Hunter Region are established, leaf fluoride concentrations as high as 48 μg/g seem to have shown no damage on the vineyards. The ambient atmospheric concentration recommended as a threshold for an average of a growing season is 0.1 $\mu g/m^3$, which is more stringent than that suggested in Table 51. The results for Western Australian vineyards cited in the SPCC Report indicate that leaf damage in sensitive grapes is noticeable at around 30 μg/g of dry leaf and at ambient concentrations above 0.1 $\mu g/m^3$ average during the growing season.

James *et al* (1983) have used the SCA model referred to in the previous section to obtain estimates for the future operations of the Tomago and Kurri Kurri aluminium smelters. The results show a significant increase in fluoride levels in the north-east of the Lower Hunter Region with the new Tomago smelter in operation. Their model predicts that the annual average concentration of total fluoride in the region between Kooragang Island and Raymond Terrace will increase from 0.1–.15 $\mu g/m^3$ to 0.15–0.2 $\mu g/m^3$ with the smelter in operation. Around Tomago itself they suggest the levels will rise to 0.5 $\mu g/m^3$.

TABLE 51 Fluoride effects

Ambient fluoride levels	ppm	$\mu g/m^3$	Damage
VEGETATION			
long-term (growing season)	.00033-.00077	0.3-0.7	5% injury to sensitive plants (grapes, gladioli, peach, plum, sorghum)
	.00055-.00220	0.5-2.0	5% injury to intermediate plants (most grasses, barley, rye, citrus, oats)
	.00110-	1.0-	5% injury to resistant plants (lucerne, most vegetables)
1 month	.00055-.00110	0.5-1.0	5% injury to sensitive plants
	.00110-.00550	1.0-5.0	5% injury to intermediate plants
	.00330-	3.0-	5% injury to resistant plants
1 week	.00083-.00220	0.75-2.0	5% injury to sensitive plants
	.00165-.00880	1.5-8.0	5% injury to intermediate plants
	.00770-	7.0-	5% injury to resistant plants
short-term 8 hours	.00220-.00660	2.0-6.0	5% injury to sensitive plants
	.00550-.00330	5.0-30.0	5% injury to intermediate plants
	.02750-	25.0-	5% injury to resistant plants
12 hours	.00165-.00550	1.5-5.0	5% injury to sensitive plants
	.00440-.0297	4.0-27.0	5% injury to intermediate plants
	.0242-	22.0	5% injury to resistant plants
24 hours	.00110-.00440	1.0-4.0	5% injury to sensitive plants
	.00330-.02200	3.0-20.0	5% injury to intermediate plants
	.0165-	15.0	5% injury to resistant plants
	(forage)	(average equivalent contributing ambient $\mu g/m^3$)	
ANIMALS			
More than 3 months	40	1.0	Significant incidence of lameness in dairy cattle, effects on growth, milk production, severe osseous lesions and dental fluorosis.
More than 2 months	60	1.5	
More than 1 month	80	2.0	
Yearly average	40	1.0	Chemical evidence of fluoride ingestion, discernable but non-damaging bone lesions, changes in dentition which do not affect wearing quality.

The ambient effect for Alcan with increased production but improved emission control technologies, as estimated by James *et al*, is a decrease over 1979–80 emission conditions in the seasonal average of fluoride concentrations in neighbouring vineyards, with all predictions below the SPCC limit of 0.1 $\mu g/m^3$. However, there would be a 14 km^2 area around the smelter with concentrations of gaseous fluoride above 0.2 $\mu g/m^3$ for a seasonal average and an area between 5–10 km^2 with levels above 0.5 $\mu g/m^3$. James *et al* suggest 'these levels will almost certainly cause moderate to severe damage to vegetation and possibly induce fluorosis in animals'. James *et al* (1983) also note that the meteorological conditions assumed in the model are averages taken at Cessnock over the period 1976–80. Thus the estimates for the concentrations at the vineyards may be higher in certain seasons than the 0.08 $\mu g/m^3$ predicted. James *et al* also report that the fluoride emissions from the power stations have negligible effect (as shown in Chapter 4 for the Upper Hunter power stations).

In Chapter 5 it was noted that acid gas mean levels could be expected to vary up to 50 per cent over a 30 year period due to meteorological fluctuations alone. This supports the caution stressed by James *et al* about future fluoride levels since the SPCC limit of 0.1 $\mu g/m^3$ is for a relatively short meteorological data base and it is predicted to be near violation. Certainly the aluminium smelter planned at Lochinvar could have been expected to increase the levels.

Some monitored data collected by the Kurri Kurri and Tomago aluminium companies have been supplied to us by the SPCC. These recordings are now briefly discussed. It should be appreciated that because of the measurement method used and the effect of sampling errors, there is a more than usual unreliability associated with these data.

Kurri Kurri data

In Table 52 the gaseous fluoride concentrations recorded at a number of stations are shown for 1983 and 1984. It is clear that a growing season average of 0.1 $\mu g/m^3$ is not being exceeded at the vineyards monitored, if the annual average is studied, but is clearly in danger if the monthly averages are considered. The results underline the need for continued monitoring in the area.

The fluorine content ($\mu g/g$ dry weight) in vine leaves at various vineyards is shown in Table 53. Generally these results support the work cited elsewhere by the SPCC report: that if the ambient gaseous fluoride levels are below 0.1 $\mu g/m^3$ then the fluorine content in leaves is less than the standard of 25–30 μg/g. It is noticeable too from these results that there is some danger in allowing any new industry into the area that adds significantly to the fluoride emissions.

TABLE 52 Kurri Kurri gaseous fluoride data (μg/m^3)

Site	Location$^+$	Annual average* 1983	Annual average* 1984	Max. monthly average* 1983	Max. monthly average* 1984
Yawarra	SE2	.23	.58	.62	1.6
Res # 61	S1.08	.08	.09	.24	.15
J. Van Acker	WNW3	.12	.08	.28	.22
Bishops Bridge	NW5	.05	.07	.13	.16
Rothbury Estate	W16	.06	.05	.12	.09
McWilliams	W18	.05	.05	.17	.11

$^+$ SE2 = 2 km SE of Alcan smelter, etc.

* 1984 data only for Jan-Sept.

Examination of the fluoride content in forage near Kurri Kurri yields a similar result. Forage within a few kilometres of the smelter exceeds the suggested levels given in Table 51 (up to a yearly average of 71 ppm, and a monthly average of 252 ppm) but not beyond a 5 km radius. In fact, the two sites which have yielded the highest levels are within 2 km of the plant and hence in the buffer zone owned by the company. While there is some grazing between 2 and 5 kms, the levels monitored are acceptable in this zone. The fluoride analysis of citrus fruits and vegetables 8–14 km away also indicates low levels. An analysis of fluorine levels in sensitive vegetation such as *Angophora bakeri* and *Eucalyptus maculata* indicates that in 1983–84 annual averages were not above 50 μg/g up to 5 km from the smelter.

The monitored data reported in Tables 52 and 53 for the Alcan smelter are the result of emissions from Lines I and II. Line III began operation in early 1985 and adds up to 50 per cent to the recent overall emission load. However, there is not expected to be any increase over 1983–84 levels because of recent control introduced on emissions from the bake plant (Mitchell 1985). Given the unreliability that is presently associated with monitored data and the potential for meteorological influences not present in 1983 and 1984, the following is clear: first, continued ambient, vegetation and forage monitoring in the area is warranted; and second, any further emission increases in the area impinged by the Alcan smelter, as would haved occurred with a smelter at Lochinvar, must be considered with extreme caution. In Chapter 8 a particular policy approach is proposed for ensuring that fluoride emissions be kept within reasonable limits to avoid damage to sensitive receptors such as grapevines. It is an incentive policy based upon pollution taxes in proportion to actual fluoride levels measured in vegetation species.

TABLE 53 Fluorine in vine leaves (μg/g dry weight) near Kurri Kurri

		1983/84						Previous Season
Site (grape)	Location	Oct	Nov	Dec	Jan	Feb	Mar	Av.
Millstone (Shiraz)	NW 10	3	8	10	10	19	29	16.9
George Hunter Estate (Shiraz)	WNW 11	8	24	7	11	13	15	19.1
Allandale (Semillon)	NW 11	6	14	9	9	9	7	11.4
Bellbowrie (Semillon)	WNW 15	3	5	9	9	15	7	14.0
Lakes Folly (Shiraz)	W 13	7	3	8	10	15	17	11.6
Seppelts Pokolbin (Shiraz)	W 12	2	6	9	13	13	13	18.7
Rothbury Estate (Shiraz)	W 16	5	9	9	11	10	9	12.4
Mc Williams (Shiraz)	WSW 18	6	6	7	9	11	15	12.0
Tyrells (Shiraz)	W 19	7	6	8	11	13	13	15.9
Tomalee Estate (Shiraz)	NNW 16	6	10	8	20	15	8	11.2
Wyndham Estate (Shiraz)	NNW 16	5	3	7	7	10	12	10.6
Glen Elgin (Shiraz)	WSW 17	13	7	10	13	14	8	17.5

Tomago data

Fluoride data around the Tomago aluminium smelter are available from December 1983, quite soon after the commencement of operations. The gaseous fluoride levels monitored are shown in Table 54. It would appear that the impact of the smelter is noticeable within 1–2 km. The monitoring network data supplied to us are not widespread enough to assess the impact further away although it would appear that monthly average levels of the order of 0.06–0.10 μg/m^3 may be expected up to 5 km away. An analysis of the fluorine content of vegetation does not reveal any significant effects beyond a kilometre of the smelter, at this stage.

Tomago plant became fully operational on October 26, 1984. The data in Table 54 do not go beyond July 1984 and therefore do not allow assessment of the full impact of the smelter. However, the State Pollution Control Commission report (Dean 1985) that total emissions of fluoride are quite low at around .46 kg/tonne of aluminium. This figure is in contrast to levels expected in the early 1980s of about 0.6–0.8 kg/tonne (Mitchell 1985).

TABLE 54 Monthly average gaseous fluoride levels ($\mu g/m^3$) near Tomago

Location* of site	NE3.5	W1.4	E1.7	NW4.6	S1.1	NW1.7
1983						
Jan	.01	.01	.01	.01		
Feb	.02	.01	.01	.02		
Mar	.02	.02	.01	.01		
April	.02	.03	.02	.03	.06	.04
May	.03	.03	.03	.03	.03	.05
June	.02	.01	.01	.02	.03	.04
July	.04	.03	.03	.02	.06	.04
Aug	.03	.03	.02	.04	.02	.02
Sep	.05	.04	.01	.02	.07	.05
Oct	.05	.11	.07	.02	.05	.05
Nov	.02	.06	.03	.02	.06	.02
Dec	.02	.22	.04	.02	.12	.03
1984						
Jan	.05	.05	.01	.01	.12	.16
Feb	.02	.04	.03	.02	.07	.04
Mar	.03	.06	.04	.03	.05	.05
April	.04	.04	.06	-	.06	.06
May	.10	.08	.10	.06	.07	.04
June	.06	.05	.15	.06	.09	.05
July	.05	.03	.19	.05	.08	.05

* NE3.5 = Site 3.5 km NE of Tomago smelter.

[illegible] fluoride content of vegetation [illegible] beyond a [illegible] of the smelter [illegible]

[illegible] plant became fully operational on October 24, 1984. The data in Table 34 do not go beyond July 1984 and therefore do not allow assessment of the full impact of the smelter. However, the State Pollution Control Commission report (Tang 1985) that total ambient gaseous fluoride levels are quite low at around .46 [illegible] This figure is similar to levels reported in the early 1980s of about 0.6–0.8 μg/m³ (Mitchell 1983).

TABLE 34. Monthly average ambient fluoride levels (μg/m³) near [illegible]

[illegible]

Fluoride data around the [illegible] smelter [illegible] December 1984, subsequent to the commencement of operation. The gaseous fluoride levels measured are shown in Table 36. It would appear that [illegible]

7

Pollution from mobile sources

Introduction

The contribution of mobile sources to pollution levels in the Hunter Region is largely unknown since little specific monitoring of related ambient concentrations has been carried out. In Chapter 5, the combined effect of stationary and mobile sources was assessed for the Newcastle urban area. Suggestions were made first, as to the increase in emissions which could be tolerated with minimal risk; and second, as to the type of monitoring which should be used to complement the present scheme. Particular emphasis was placed on the need to monitor nitrogen oxides to determine their contribution to the level of acid gases and to appreciate the potential threat to ozone formation.

In this chapter the future risks of pollution from mobile sources outside the Newcastle area are identified. It is anticipated that pollutant levels will not be a significant problem on the open road where rapid dispersion can take place. Consideration has been given to locations where road use will be concentrated; where structures are present to reduce the dispersion of pollutants; and where a relatively large population is at risk. Singleton, Maitland and Muswellbrook were chosen as towns worthy of investigation since they will be subject to increasing traffic throughput, especially from heavy duty vehicles a large proportion of which are directly involved with the coal industry. The pollutants generally of concern in such situations are carbon monoxide and nitrogen oxides. A simple computation of the ratio of these emissions to particulates revealed the latter to be of minor significance.

While the prediction of volumes of road haulage of coal is difficult and hindered by the high fluidity of short-term mine needs (Keech 1983) it is expected that the traffic throughput in the towns under study will increase. Indeed the importance of road haulage as a coal transport mode is certain to continue despite the NSW Government's stated policy of using rail transport where practicable. Since road transport is generally economic over short distances it is mainly utilised for the movement of coal to rail loader or treatment plant. However, its high flexibility of operation and its current position as the only real alternative to rail shipment strengthens its role in the transport system. For example, any short-term under-capacity by rail or conveyor tends to be met by the use of road transport.

Methodology

Estimates of ambient concentrations of pollutants generated by motor vehicles from existing or proposed roadways are generally obtained by application of deterministic mathematical dispersion models. These models vary in complexity from simple approaches, such as the Gaussian line source assumption, to those based on the conservation of pollutant mass equation, which may require sophisticated numerical methods of solution.

To obtain estimates of ambient levels of pollutants from current and projected motor vehicle emissions in the Hunter region a stochastic Monte-Carlo simulation approach was used. As the purpose of the modelling is to determine if an air quality standard is being or could be exceeded, and if so, to what extent, it is useful to obtain these estimates in terms of probability distributions so that the frequency of exceedance of a specified pollution level can be determined. Thus, once more it is the upper percentiles of the distribution of pollution concentration or at least the maximum concentration that are required.

Unfortunately it is the prediction of the highest concentrations for which deterministic models in general and accepted line source models in particular are not applicable. Maximum pollutant concentrations usually occur during periods of variation in atmospheric stability and such variations are difficult to describe mathematically. On the other hand, it is known and has been demonstrated in Chapters 4 and 5 that the sample frequency distribution of pollution measurements very often can be parameterised by probability distributions with 1, 2 or 3 parameters. Once the functional form of such a distribution has been identified for a given monitoring site, its parameters and hence its upper percentiles can be estimated if a small number of points on the curve can be predicted. The parameters of the curve will vary with emission source strength and with meteorology.

Two deterministic models have been adopted in this simulation study, one an area source model and the other a line source model. The methodology invokes the two deterministic models over the range of conditions for which they are most applicable thereby predicting points on a probability-concentration curve with an assumed parametric form. For the deterministic models used here these points are the mid-percentiles. By fitting such points to the curve other points including the maximum of the distribution can be inferred. Uncertainties in the source strength of a pollutant are taken into account by stochastic variation of emission levels. Variation in the windspeed distributions is incorporated by producing separate model outputs for a range of wind speed regimes provided ideally by historical analysis. The methodology is particularly useful when no pollution measurement data are available, as the results of the simulation exercises can be presented in a sufficiently informative and comprehensive form to indicate whether monitoring should be undertaken.

The parametric form assumed in this study for the distribution of pollution concentration is a two-parameter lognormal curve although other parametric forms may be applied. However, in the absence of detailed knowledge of the true parametric form, the lognormal assumption is to be preferred. Stochastic simulation using the two deterministic models has yielded consistent results, in that the area model yields median and maximum concentrations equivalent to those generated by the line source model some distance from the roadway.

The pollutant dispersion models

The two complementary deterministic models are employed separately in this simulation study to produce points on a parametric curve. The first model is the Atmospheric Turbulence and Diffusion Laboratory model which yields average pollutant concentrations for the area. The second is a Gaussian plume line source model, the General Motors (GM) model, which allows for estimation of the variation of pollutant concentration with distance from the roadway. These are reasonably simple models. Nevertheless, numerous investigations have shown that simple modelling approaches may be used to estimate ambient concentrations resulting from the dispersion of pollutants in an airshed. Further, it has been shown that the results from such simple models compare quite well with more complex models (Simpson and Hanna 1981).

The ATDL model has been shown to yield predictions which compare favourably with those given by far more complex models and has been demonstrated to be applicable to a wide range of urban environments in the USA, Europe (Hanna and Gifford 1977) and to Canberra, Australia (Daly and Steele 1975, 1976). The ATDL model is applicable to urban area sources in which the emissions are assumed uniform over grid squares which may vary in size from 1 to 10 km square. Appendix VI gives more details of this model.

Of course, estimates of air quality adjacent to proposed or existing roadways are also made with more complex models. A detailed experimental comparison of the capability of eight well-known deterministic models including the HIWAY model used by the USEPA was undertaken by Sistla *et al* (1979) The relatively simple GM model gave best agreement with observed pollutant concentrations and hence was the line source model chosen for this study.

The GM model uses a Gaussian line source approach but avoids the assumption used in HIWAY that the line source is an indefinite number of point sources by considering the line source to be of infinite length. It calculates the concentrations at height z above the ground and distance x from the source using the equation given in Appendix VI. It is known that dispersion characteristics will change as some function of wind direction relative to the road. When the wind is nearly parallel to the road, it is expected that pollutants from the upwind portion of the line source (relative to a fixed receptor) would be significantly dispersed before they arrive at the receptor. In this study wind direction has been assumed to be at right angles to the roadway, an assumption which will yield an upper bound to the estimate of pollution concentration.

Both the area and line source models make the assumption that no chemical reactions involving the pollutant gases will occur. Carbon monoxide is essentially unreactive and is observed to decrease in concentration only by dilution. In the case of NO_x, consisting of nitric oxide (NO) and nitrogen dioxide (NO_2), it is recognised that these compounds may undergo a complex series of photochemical reactions during dispersion from the roadway. At the exhaust pipe of the motor vehicle, the overwhelming majority of the emitted NO_x is present as NO. The subsequent conversion of NO to NO_2 is relatively rapid as it reacts with oxygen in the air.

The Larsen model

The dispersion models discussed in the previous section are applicable only under certain conditions. For instance both the ATDL and GM models are not accurate at wind speeds below 1 ms^{-1}. In fact, the models predict only mean concentrations adequately and not extreme events. As detailed in Appendix V, Larsen (1969, 1971) has developed a methodology to estimate cumulative frequency distributions from which may be derived the maximum expected concentrations and the frequency with which a given standard is equalled or exceeded. Larsen made the assumption that air pollution data may be represented by a two-parameter lognormal distribution with parameters α and β which are the geometric mean and geometric standard deviation, respectively. The maximum concentration, χ_m, is estimated as

$$\chi_m = \alpha \, \beta^{Z_{max}} \tag{7.1}$$

where Z_{max} is the value of Z (the number of standard deviations from the mean) for the highest concentration (eg $Z_{max} = 3.81$ for hourly averages and a one year data set).

The application of the ATDL model in conjunction with the Larsen model has successfully been employed to predict both maximum total suspended particulate concentrations and maximum CO concentrations (Simpson *et al* 1983). It has been used in Chapter 5 to obtain estimates of maximum sulphur dioxide concentrations originating from low level sources in the Newcastle area. The method involved using only the range of moderate to high wind speed values for which the ATDL model has been shown to work best ($u \geq 2$ ms^{-1}). The ATDL model is used only to predict a portion of the distribution of concentration from the moderate to high distribution of wind speeds. In other words, the ATDL model is not used to predict the relationship between wind speed data and concentration data monitored at the same time when other factors such as atmospheric stability could be expected to have additional influence on concentration values. Such factors empirically appear to be of limited significance when describing pollution concentration in a distributional sense (Simpson *et al* 1985).

With both the ATDL model and the GM model an inverse power law dependence is assumed between the air pollutant concentration and the wind speed. It can be shown that if the wind speed data are lognormally distributed such an assumption implies that the air pollution concentration data are also lognormally distributed with the same logarithm of the geometric standard deviation (log β). Therefore the wind speed data can be used to estimate β. The median value of the air pollution concentration data can be estimated using the ATDL or GM model. Once the median (which is α) is known as well as β, then the maximum concentration may be determined via (7.1). In this way the deterministic and statistical components are combined to relate emission strengths to maximum values.

The geometric standard deviation, β, is calculated according to

$$\beta = \exp\left[\frac{\ln \chi_n/\chi_i}{Z_n - Z_i}\right] \qquad (7.2)$$

where χ_n and χ_i are the windspeeds occurring at Z_n and Z_i respectively, and Z is the number of standard deviations from the median. The windspeeds, χ_n and χ_i, may be read off a cumulative frequency distribution plot of the logarithm of windspeed against Z (a lognormal probability graph); in this chapter n and i refer to the 1-st and 50-th percentile points. Fig. 40 presents these plots for the 1980 and 1981 windspeed data sets.

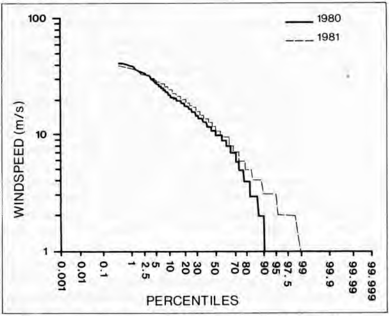


FIGURE 40 The distribution of hourly wind speeds for 1980 and 1981

Simulation approach

Monte-Carlo simulations were performed to obtain estimates of both median and maximum ambient pollution concentrations. The median is useful as an indication of average values whereas the maximum is of importance as a comparison with air quality standards which are generally written in terms of an allowable number of exceedances (usually zero or one) of a given concentration per year.

It is appropriate to run such simulations with input meteorological data representative of the location's meteorological conditions. Also because the number of exceedances of a standard are specified for calendar years, the modelling exercises are carried out separately for individual years using recordings available. Ideally, all calendar years of historical records would be used and the results classified according to the type of meteorological year (for example, according to average hourly wind speeds and standard deviation) and its frequency of occurrence. Here results are reported for two years which have different meteorological regimes.

The traffic data used are averages obtained from a number of counts made by the New South Wales Government Transport Study Group over a 1 to 2 year period. However, a particular one day count made by local citizens was also available. These data showed traffic levels to be about 20 per cent higher than the government count for light duty vehicles and about 25 per cent higher for heavy duty vehicles. On this basis, and in the absence of more detailed information, the traffic inputs for a particular hour were chosen as random samples from a uniform distribution with the mean taken as the reported average of the longer term count and with a non-zero range extending 20 per cent above and below the mean.

The Monte-Carlo simulation exercises were performed 185 times for each year of meteorological data, for each hour of the year and for each traffic count scenario to obtain the maximum and median ambient concentrations. The choice of 185 iterations stems from work by Spear (1970) on systems considered to be describable by well-defined structural models whose parameters are related to the physics of the system but whose uncertainty may be better defined by an a priori parameter distribution rather than by point parameter estimates. Spear has shown that for estimating the true population distribution $F(z)$ of a system scalar variable of interest z, for example, the median and maximum concentration, a Kolmogorov statistic can be used to provide a measure of the accuracy of the sample distribution function $S_n(z)$ generated by n repeated Monte-Carlo simulations of the system. In fact, to achieve a given accuracy the number of samples n from the parameter distributions is independent of the number of system parameters and their distributions.

Basically, $n = 185$ has been chosen here because it satisfies the following probability relationship

$$P(S_n(z) - 0.1) \leq F(z) \leq P(S_n(z) + 0.1) = 0.95$$

That is, F(z) lies within the bounds $S_n(z)$ ± 0.1 with 95 per cent confidence. This seems a reasonable accuracy to obtain, particularly when it is realised, for example, that n = 2055 simulations are required to reduce the error bound from 0.1 to 0.03.

The algorithm used to simulate the hourly median and maximum ambient pollution concentrations resulting from roadway line source emissions over a year is comprehensively detailed in Jakeman *et al* (1984a). For the benefit of the reader a schematic illustration of the algorithm is provided in Fig. 41.

The data

Traffic counts

Heavy and light vehicle counts for the Hunter Region were obtained from the State Transport Study Group of NSW. The data consisted of 1 to 5 day counts averaged over several years. The data for Singleton compare well with a recent independent one day study (Anon 1982). Table 55 lists these data. The one day study fortunately comprises an hourly breakdown which was used to stratify the average daily data into 12 average hourly counts for the important 6 am–6 pm period.

Diurnal variation in traffic counts

Source strengths of pollutants for both the ATDL and GM models were partly derived from the 12 hour traffic counts (6 am–6 pm). The diurnal variation in traffic movements was determined from the hourly counts of Table 40 under the assumption that the Singleton hourly data were also representative for Maitland and Muswellbrook.

For each hour from 6 am to 6 pm the fraction of the total 12 hour vehicle movements, for both light duty and heavy duty vehicles, was calculated. The vehicle movement for each hour was then selected from a rectangular distribution with a range of 20 per cent above and 20 per cent below average diurnal values.

Wind speed

The wind speed data were those recorded by the NSW Electricity Commission at Liddell for the two year period 1980–81. Liddell is the closest meteorological station to Singleton, Maitland and Muswellbrook with useful records. The wind speed data were provided as one hour averages. Fig. 42 illustrates the average diurnal variation of the Liddell wind speed data for 1980 and 1981. In conjunction with the traffic data of Table 56, it highlights the potential problem periods of the day for pollution from motor vehicle transport, viz around 8 am and 4 pm.

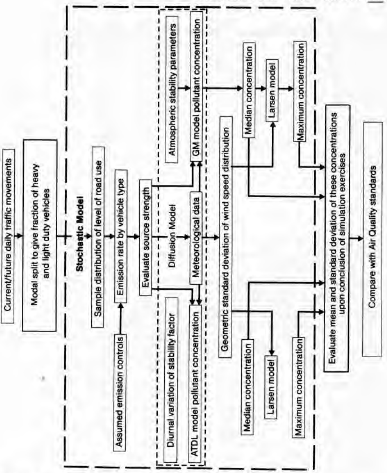


FIGURE 41 Major steps in the simulation algorithm. The stochastic model portion represents one Monte-Carlo simulation exercise for a calendar year

It should also be emphasised that while average values obtained for each year show close correspondence, the average values do not reflect the differences in actual distributions of wind speeds between the two years. Fig. 40 gives the distributions and, as will be shown, the differences of frequencies in the low wind speed range lead to the prediction of different pollutant maxima. Therefore it is necessary to analyse available historical wind speed records in order to gain comprehensive information regarding the potential impact of pollutant emissions from roadways.

TABLE 55 Traffic counts in Singleton at the Dunolly Bridge

Time Period	Coal Trucks	Other Trucks	Cars
6–7[a]	37	67	810
7–8	45	29	600
8–9	90	86	1000
9–10	33	124	832
10–11	30	138	712
11–12	35	138	935
12–13	47	184	857
13–14	51	94	1000
14–15	34	196	1330
15–16	23	104	1071
16–17	12	197	1795
17–18	13	45	1097
Total	450	1402	12039
12 hour Average[b]		1359	8883

(a) Source: Anon (1982).

(b) N.S.W. State Transport Study Group average for a number of counts extending from 1–5 days.

TABLE 56 Light duty vehicle emission rates

Pollutant	Regulation	Emission Rate (g/km)	Fraction of Vehicles (per cent)
CO			
Pre–1974	ADR 26	44.88	26.2
1974–76	ADR 27	42.59	12.3
1976–77	ADR 27I	16.56	16.3
1978–80	ADR 27II	14.75	29.4
1981–82	ADR 27III	12.47	15.8
1985	US 75	8.51	—
NO_x			
Pre–1974	ADR 26	2.13	26.2
1974–76	ADR 27	2.35	12.3
1976–77	ADR 27I	1.99	16.3
1978–80	ADR 27II	1.65	29.4
1981–82	ADR 27III	1.65	15.8
1985		1.65	—

Source: Aust. COMVE (1982).

Motor vehicle exhaust emission rates

Motor car pollutant exhaust emission rates are also required to calculate source strengths. The rates are currently regulated by Australian Design Rules (ADR26 and ADR27). Table 56 lists the exhaust emission rates under existing and Australian Design Rules proposed for 1985 in 1982. Those actually introduced in 1986 as ADR37 are very close to those

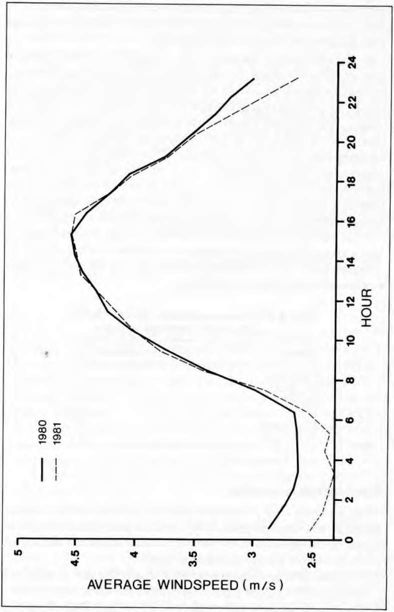


FIGURE 42 **Average diurnal variation of Liddell wind speed data for 1980 and 1981**

proposed and do not significantly affect the simulation results. The fraction of the total motor car population to which the respective design rules apply is also listed as at January 1982.

In Australia exhaust emission rates of heavy duty diesel powered vehicles for carbon monoxide and nitrogen oxides remain uncontrolled. No data are available from the NSW State Pollution Control Commission giving emission rates of CO and NO_x for heavy duty diesel powered vehicles. Data employed were therefore derived from American studies (Stern 1977; USEPA 1977). Table 57 lists the pollutant emission rates for heavy duty diesel powered vehicles. These emission rates represent uncontrolled emissions averaged over a number of heavy duty diesel powered motor vehicles operating under a variety of conditions. While these data were reported in 1975, it is expected that these emission rates have not changed significantly from the uncontrolled emission rates.

It has been assumed that no deterioration occurs in these emission rates with age and that no tampering with emission controls takes place. Thus the Australian Design Rule emission rates are likely to be a lower estimate of actual exhaust emission rates.

TABLE 57 Exhaust emission rates for heavy duty diesel powered vehicles

Pollutant	Truck emission (g/km)
Particulates	0.81
SO_x as SO_2	1.7
CO	17.8
HC	2.9
NO_x as NO_2	13.0
Organic acids	0.2

Source: Stern (1977).

Simulation scenarios

Three scenarios were prepared for each of the three towns Singleton, Maitland and Muswellbrook. The scenarios were based on current, projected and potential motor vehicle pollutant emission rates and vehicle movements and are described as follows:

- The first scenario represents the current situation and employs estimated pre 1985 vehicle emission rates and 1983 traffic level estimates.
- The second scenario, projection 1, is for the year 2000. It reduces exhaust emission rates of motor cars to average values as specified by Australian Design Rules (see Table 56). The emission rates for motor

cars at the year 2000 were derived from data giving vehicle age against fraction of vehicle kilometres travelled, VKT, (Aust., COMVE 1982) and relating vehicle age to the appropriate design rule. For heavy duty diesel powered vehicles no design rules apply or are presently envisaged for the control of CO and NO_x emission rates. Vehicle movements are assumed to grow by 4.5 per cent per annum. This is the estimate of road use increase in the Singleton Central Business District taken from the Singleton Planning Study (Bergsteiner, McInnes and Rigby Pty Ltd 1976). For Muswellbrook a similar estimate was obtained from the Muswellbrook Environmental Study. For Maitland, the 4.5 per cent figure was merely assumed.

- The third scenario, projection 2, is the same as projection 1 with the exception that emission rates for heavy duty diesel vehicles have been reduced to 1981 levels required in the United States (National Research Council, Motor Vehicle Nitrogen Oxides Standard Committee 1981).

Table 58 lists the vehicle emission factors and the traffic movement data for the three scenarios.

Simulation results

For the three scenarios the estimated ambient concentrations of the pollutants CO and NO_x have been evaluated. Table 59 lists these data for Singleton. All concentrations in this table are given as 1 hour averages. The values reported are for both years for which wind speed data are presently available. Fortunately, the two wind speed years are sufficiently different as to be representative of a broad spectrum of regimes. In Table 59, for each year of wind speed data, the median and maximum estimated pollutant concentrations are reported. These are in terms of averages and standard errors for the 185 simulations.

The corresponding 8 hour averages determined by application of the ATDL model on Singleton are given in Table 60. These 8 hour averages were derived from the 1 hour average data for the 8 am–4 pm period. Ambient concentrations of pollutants were estimated at distances of 100–500 m in 100 metre intervals from the roadway edge using the GM model. The results for Singleton are listed as the maximum 1 hour averages in Table 61 for the first scenario which represents the current situation. As would be expected pollutant levels are considerably higher at 100 m from the roadway than those estimated by the ATDL model. However, pollutant concentrations rapidly fall with distance, that is with dispersion from the roadway. Thus the GM model provides a good

TABLE 58 Vehicle emission factors and traffic counts

Scenario	Average 12 hour traffic count				Emission rate (g/km)	
		Maitland				
	Singleton	Main	Bypass	Muswellbrook	CO	NO_x
Current						
Motor car	8,883	13,447	6,669	11,814	25.77	1.92
Heavy duty diesel	1,359	915	1,291	1,131	17.8	13.0
Projection 1						
Motor car	27,000	32,500	16,000	26,000	8.75	1.65
Heavy duty diesel	4,000	2,200	3,100	2,700	17.8	13.0
Projection 2						
Motor car	27,000	32,500	16,000	26,000	8.75	1.65
Heavy duty diesel	4,000	2,200	3,100	2,700	8.9	6.5

TABLE 59 Ambient median and maximum 1 hour pollutant levels for Singleton, derived from the ATDL simulation

Scenario	Wind speed data set[a]		Pollutant	
			CO(ppm)	NO_x(pphm)
Current Situation[b] (1983)	1980	median	0.13 ± <.01	1.54 ± 0.02[e]
		maximum	0.71 ± 0.02	8.53 ± 0.08
	1981	median	0.15 ± <.01	1.85 ± 0.02
		maximum	0.85 ± 0.03	10.25 ± 0.11
Projection 1 (2000) (Current vehicle emissions)[c]	1980	median	0.15 ± <.01	4.23 ± 0.06
		maximum	0.84 ± 0.02	23.41 ± 0.33
	1981	median	0.18 ± <.01	5.07 ± 0.10
		maximum	1.01 ± 0.02	28.10 ± 0.58
Projection 2 (2000) (Reduced vehicle emissions)[c][d]	1980	median	0.14 ± <.01	3.19 ± 0.05
		maximum	0.76 ± 0.03	17.65 ± 0.28
	1981	median	0.16 ± <.01	3.82 ± 0.08
		maximum	0.91 ± 0.02	21.14 ± 0.42

(a) N.S.W. Electricity Commission wind speed data recorded at Liddell.

(b) Based on the Department of Motor Transport road use counts for the Hunter Valley.

(c) Based on the road use levels projected for the 1990s given in *Singleton Planning Study*, prepared for the Singleton Shire Council by Bergsteiner, McInnes and Rigby Pty. Ltd. (1976).

(d) Reduced vehicle emissions, based on ADR 27A111 and the US 75 design rules. Truck emissions have been reduced 50% in line with anticipated US reductions.

(e) Standard error.

qualitative measure of the likely variation of pollutant concentrations from the roadway. The relative change in pollutant levels is illustrated in Fig. 43. It should be noted that wind direction will influence dispersion from the roadway. Fig. 43 illustrates dispersion when the downwind direction is at right angles to the roadway. As the angle between wind direction and the roadway falls so dispersion from the roadway will fall.

TABLE 60 Ambient median and maximum pollutant levels as 8 hour averages for Singleton, derived from the ATDL simulation

			Pollutant	
Scenario	Wind speed data set		CO(ppm)	NO_x(pphm)
Current	1980	median	0.076	1.087
		maximum	0.280	3.976
	1981	median	0.080	1.096
		maximum	0.289	4.006
Projection 1	1980	median	0.097	3.046
		maximum	0.354	11.147
	1981	median	0.101	3.069
		maximum	0.362	11.229
Projection 2	1980	median	0.085	2.157
		maximum	0.310	7.876
	1981	median	0.086	2.176
		maximum	0.311	7.940

TABLE 61 Ambient maximum pollutant levels as 1 hour averages for Singleton, derived from the GM simulation for the current situation

	Pollutant			
	CO(ppm)		NO_x(pphm)	
Distance (metres)	1980	1981	1980	1981
100	3.08 ± 0.06	3.71 ± 0.08	36.62 ± 0.52	44.41 ± 0.89
200	0.56 ± 0.02	0.67 ± 0.03	6.78 ± 0.10	8.18 ± 0.17
300	0.32 ± 0.02	0.38 ± 0.02	3.69 ± 0.05	4.44 ± 0.09
400	0.22 ± <.01	0.27 ± 0.02	2.54 ± 0.04	3.06 ± 0.06
500	0.17 ± <.01	0.20 ± 0.02	1.94 ± 0.03	2.34 ± 0.05

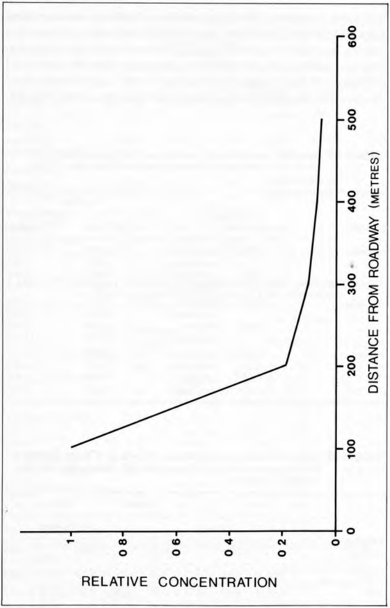


FIGURE 43 **Relative concentration of dispersed pollutant with perpendicular distance from the roadway emission source according to the GM model**

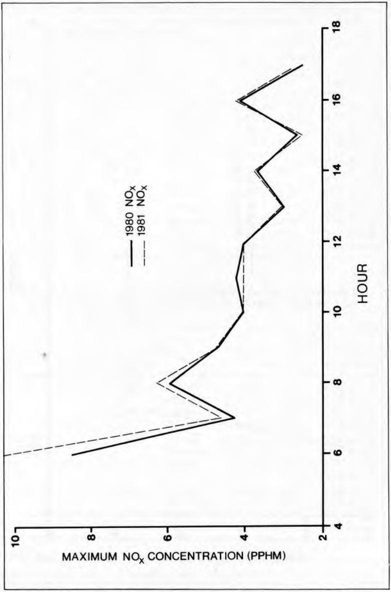


FIGURE 44 Average diurnal variation of maximum concentrations of nitrogen oxides in Singleton simulated for current emissions situation using 1980 and 1981 wind speed data

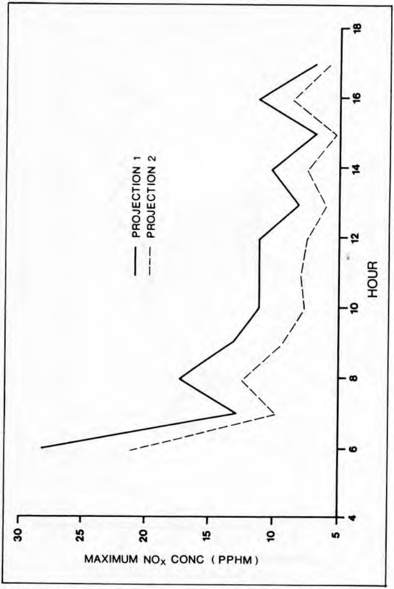


FIGURE 45 Average diurnal variation of maximum concentrations of nitrogen oxides in Singleton simulated for projection 1 and projection 2 using 1981 wind speed data

TABLE 62 Ambient median and maximum pollutant levels as 1 hour averages derived from the ATDL simulation for Maitland (main street)

Scenario	Wind speed data set		Pollutant	
			CO(ppm)	NO$_x$(pphm)
Current	1980	median	0.18 ± 0.01	1.72 ± 0.03
		maximum	1.02 ± 0.03	9.52 ± 0.16
	1981	median	0.22 ± 0.01	2.07 ± 0.04
		maximum	1.23 ± 0.03	11.46 ± 0.23
Projection 1	1980	median	0.16 ± <.01	3.72 ± 0.06
		maximum	0.90 ± 0.02	20.63 ± 0.33
	1981	median	0.20 ± 0.01	4.50 ± 0.09
		maximum	1.09 ± 0.03	24.91 ± 0.51
Projection 2	1980	median	0.15 ± <.01	3.16 ± 0.05
		maximum	0.85 ± 0.03	17.49 ± 0.29
	1981	median	0.18 ± 0.01	3.80 ± 0.08
		maximum	1.03 ± 0.03	21.05 ± 0.43

TABLE 63 Ambient median and maximum pollutant levels as 1 hour averages derived from the ATDL simulation for Maitland (bypass)

Scenario	Wind speed data set		Pollutant	
			CO(ppm)	NO$_x$(pphm)
Current	1980	median	0.10 ± <.01	1.29 ± 0.02
		maximum	0.55 ± 0.01	7.15 ± 0.11
	1981	median	0.12 ± <.01	1.55 ± 0.03
		maximum	0.65 ± 0.02	8.61 ± 0.16
Projection 1	1980	median	0.10 ± <.01	2.88 ± 0.04
		maximum	0.53 ± 0.02	15.96 ± 0.24
	1981	median	0.12 ± <.01	3.48 ± 0.06
		maximum	0.64 ± 0.02	19.30 ± 0.35
Projection 2	1980	median	0.08 ± <.01	2.08 ± 0.03
		maximum	0.45 ± 0.02	11.53 ± 0.17
	1981	median	0.10 ± <.01	2.50 ± 0.04
		maximum	0.55 ± 0.01	13.85 ± 0.25

The diurnal variation of pollutant levels reveals that the maximum occurs in the morning peak period from approximately 6 am until 9 am. A similar peak occurs in the afternoon though lower than that estimated for the morning peak. The difference can be attributed to increased wind speeds in the afternoon. The average diurnal variation of maximum NO$_x$ concentrations using the ATDL model and current traffic and emission estimates is illustrated for Singleton in Fig. 44 for the wind regimes of 1980 and 1981. Fig. 45 gives the diurnal variation for maximum NO_x using emissions predicted at the year 2000 under projections 1 and 2 using the 1981 wind speed data.

Tables 62 to 64 present the corresponding results of Table 61 for the Maitland main street, the Maitland by-pass and Muswellbrook, respectively.

TABLE 64 Ambient median and maximum pollutant levels as 1 hour averages derived from the ATDL simulation for Muswellbrook

			Pollutant	
Scenario	Wind speed data set		CO(ppm)	NO_x(pphm)
Current	1980	median	0.15 ± <.01	1.61 ± 0.03
		maximum	0.85 ± 0.03	8.91 ± 0.15
	1981	median	0.19 ± 0.01	1.93 ± 0.04
		maximum	1.03 ± 0.03	10.71 ± 0.20
Projection 1	1980	median	0.19 ± <.01	3.48 ± 0.05
		maximum	0.77 ± 0.02	19.26 ± 0.29
	1981	median	0.17 ± <.01	4.19 ± 0.08
		maximum	0.92 ± 0.02	23.19 ± 0.47
Projection 2	1980	median	0.13 ± <.01	2.76 ± 0.05
		maximum	0.71 ± 0.03	15.31 ± 0.27
	1981	median	0.15 ± <.01	3.34 ± 0.06
		maximum	0.85 ± 0.03	18.48 ± 0.34

Sensitivity of the results

It is clear from Table 59 that a uniform variation in traffic levels of 20 per cent above and below the average makes little difference to the magnitude of the maximum or median. The standard errors obtained from 185 different traffic realisations in a particular wind year are quite low. Of major interest is the difference in the results between the two wind years. While the median concentration generally increases very little from 1980 to 1981 for any scenario, the maximum for 1981 results increases significantly in every case over 1980, and this is for the same traffic data.

The sensitivity of the GM model to changes in emission heights is easily demonstrated. An effective height of 1 m has been taken in the simulations, but using the formulation (A27) in Appendix VI the change in concentration for $h_0 = 0.5$ m varies from 0.5 per cent below that for

h_0 = 1 m at 100 metres from the roadway to 0.05 per cent at 500 m. At h_0 = 3.5 m the concentration increases to 5 per cent above that for h_0 = 1 m at 100 m from the roadway and to only 0.25 per cent at 500 m. It is felt that an effective emission height of 1 m is nevertheless reasonably accurate given that motor cars, which form the majority of the traffic, emit at about 0.5 metres and trucks between 1 and 3.5 m. It is certainly expected that the errors in this assumption are very much less than 5 per cent.

To obtain supporting evidence for the relevance of the lognormal assumption used in the methodology, distributions of concentrations of nitrogen oxides for the individual hours of the day accumulated over a full year period were plotted on log-probability paper using levels recorded in Canberra. This city is also an inland area about 500 km south of the Hunter Region and suffers pollution predominantly from motor vehicle sources. The graphs showed very strong lognormality, importantly for more than the upper 50 per cent of the distribution for every individual hour.

In general, it is felt that our overall results err towards overestimation for two reasons. First, the atmospheric stability values chosen for the ATDL model are for a grid square slightly larger than any of the three towns and the values in Hanna (1978) increase with grid size. Second, the wind directions for the GM model have all been assumed to be normal to the roadway, thus providing higher values. On the other hand, the models are not designed specifically to register certain high values which may occur in isolated pockets due to street canyon effects.

Environmental air quality standards and human health

Emissions of pollutants from motor vehicles in sufficiently high concentrations are recognised as a threat to public health and welfare. Table 65 lists air quality standards for nitrogen dioxide set by a number of authorities to protect public health. Air quality standards for carbon monoxide are given in Table 66. Ferris (1978) has critically examined the current US primary standards for CO and nitrogen dioxide (NO_2) and considered that these levels were adequate to protect the health of the public although he recommends an additional standard for nitrogen dioxide. This is a 1 hour maximum of 26 pphm not to be exceeded 2-3 times per year which is a little more lenient than the Californian standard and certainly more lenient than the NHMRC guideline of 17 pphm.

TABLE 65 Summary of air quality standards for nitrogen dioxide

Standard	Level of NO_2 (pphm)	Time average (hours)
USA (annual 24 hour average)	5.0	24
State of California (Maximum exposure once per year)	25.5	1
West Germany		
(Maximum long term exposure)	5.0	24
(Maximum short term exposure)	15.0	1
Canada		
(maximum acceptable)	10.0	24
	20.0	1
Victoria (proposed)		
(Acceptable level—not to be exceeded	6.0	24
more than 3 times per year)	15.0	1
(Detrimental level—not	15.0	24
to be exceeded)	25.0	1
WHO air quality goal (Maximum exposure)	10.0–17.0	1
Japan		
(Maximum exposure	2.0	24
Once per year)	5.0	1
NHMRC(a) Guideline		
(Maximum hourly exposure not to be exceeded more than once a month)	17.0	1
USSR	4.0	24

(a) National Health and Medical Research Council (Australia).

TABLE 66 Summary of air quality standards for carbon monoxide

Standard	Level of CO (ppm)	
US national primary	9.0	8 hr mean
ambient air-quality standard	35.0	1 hr maximum
WHO long term	9.0	8 hr mean
goals	35.0	1 hr maximum
Australia	5.0–20.0	8 hr mean
long term goals	.5–10.0	24 hr mean
Canada	5.0	8 hr
Japan	20.0	8 hr
USSR	0.9	24 hr

Examining the results of the simulations with the ATDL model indicates that CO levels are currently not exceeded and are not likely to be exceeded by the year 2000 in any of the towns and even the GM model simulates low CO levels near the roadways.

Of the nitrogen oxides, nitrogen dioxide poses the most serious threat to public health. Additive toxicity by other air pollutants with nitrogen dioxide is considered likely and Daly (1981) has hypothesised synergistic enhancement of the damage potential of nitrogen oxides with particulate matter and ozone.

Unfortunately, the simulations can only yield estimates of ambient concentrations of total nitrogen oxides (nitrogen dioxide plus nitric oxide). The proportion of NO_x being NO_2 is not fixed and we have observed it to vary between 1/5 and 1/2 total NO_x (Aust. Committee on Motor Vehicle Emissions 1982). For Singleton and Muswellbrook the ATDL modelling results for projections 1 and 2 produced maximum levels of total NO_x which are about double some of the more stringent standards for NO_2 and are a little higher than some of the more lenient ones. The ATDL predictions represent levels for the general town areas. For the current situation total NO_x levels very close to the roadway, as predicted by the GM model, may be of concern. However, the combined effect of the two Maitland roadways may also produce area concentrations for total nitrogen oxides near the more lenient nitrogen dioxide standards.

In summary, the simulation study estimates that CO levels are likely to remain below ambient air quality standards. By contrast, there seems a possibility that NO_2 levels may exceed at least some air quality standards at the year 2000 under current emission controls and a projected increase in vehicle kilometres travelled of 4.5 per cent (projection 1), especially in Maitland. The application of controls on heavy duty vehicles would, however, improve this situation considerably (projection 2). Our estimate of the reduction is around 20 per cent. Indeed, if further reductions in total nitrogen oxide emissions were achieved by additional control on motor cars as was achieved in the US in 1981, then a further reduction of approximately 20 per cent could be obtained. It is also possible that near the roadway even current NO_2 levels may sometimes exceed air quality standards. Therefore while the monitoring of CO is likely to be unnecessary per se, the monitoring of NO_2 would be recommended to calibrate the model and confirm the simulation results.

SECTION III

Policy approaches to air pollution control

8

Air pollution management in the Hunter region

Introduction

Chapters 3 to 7 examined the air pollution problems in the Hunter Region and highlighted a number of deficiencies in the current monitoring network. This work has also shown the difficulty in assessing air pollution impacts given the weaknesses of the mathematical models available and the fluctuations in air pollution levels due to meteorological change. Any consideration of policies on air pollution control needs to take such uncertainties into account. This chapter considers the various options available for air quality management.

Initially, a brief review of the applicable policy options is presented as well as the methodology necessary for their implementation. In particular, the use of economic tools is examined. The applicability of the various policy options is then assessed in the context of air pollution management in the Hunter Region.

Policy options in air pollution control

Given the present nature of Australian society, the presence of air pollutants is inevitable and it is questionable that even radical changes to the social organisation would lead to the significant removal of some pollutants. It is clear that there is still little known of the effect of various air pollutants on human health and on the rest of the environment (eg *see* Appendix I). Usually the data base on what is known about the emission and transport of air pollutants is limited giving rise to more uncertainty about likely impacts. Examples of this last problem abound in Chapters 3 to 7 concerning air pollution effects in the Hunter Region. There would be little disagreement with the conclusion of Baumol and Oates (1977) concerning these problems that 'in evaluating the evidence favouring a proposed protection measure, it is important to balance off the imperfection of the evidence against the magnitude of the risk from which the measure is designed to protect the public'.

In taking the anthropocentric view that human health problems should be considered as the highest priority in an air pollution control problem it has been shown in previous chapters that there are serious weaknesses in the current air pollution monitoring network in the Hunter Region. It is clearly necessary for any planning authority or control agency to decide as early as possible on the priorities to be adopted in considering air pollution problems, and for such priorities to be clearly stated to potential developers.

Having determined a set of priorities, there is a range of policy instruments which may be used in air quality management. Following the classification of Baumol and Oates (1977) these can be categorised as:

(a) moral suasion
(b) direct controls
(c) price incentives
(d) government investment.

All air pollution agencies use (a) and (d) to varying degrees through publicity, social pressure, education, dissemination of information (eg on pollution control techniques), and supporting research (eg Hawke *et al* 1978). In Australia all control agencies use (b) in their legislation through Clean Air Acts and in some cases through ambient standards or guidelines. At present there are no true price incentive mechanisms in legislation for air pollution control.

This section briefly examines the strengths and weaknesses of (b) and (c), as there is some debate about the usefulness of each.

Direct controls

From the description of NSW legislation involving air pollution control given in Appendix II, it is clear that direct controls are imposed on certain scheduled premises requiring licences to operate. Controls may prohibit certain forms of pollution. It is more usual for emissions to be reduced by imposing limits on levels of waste emissions or specifying the quality of input materials to production processes, types of equipment, and performance criteria. The air pollution control equipment adopted in each case follows negotiations between the industrial organisation and the control agency (SPCC in NSW) which uses the strategy that the best equipment be installed given the political and economic constraints involved in the industry. This is the so-called 'best practicable means' philosophy. This approach is similar to that used in the

United Kingdom and in all Australian states except Victoria (eg see Gilpin 1980; Barker 1984).

In Victoria the legislation includes a list of ambient air quality objectives which should either not be violated more than a set number of times per year, or at all. This approach is similar to that adopted in many overseas countries such as the United States, Canada, Japan and West Germany although the standards are viewed as objectives in Victoria. Barker (1984) has argued that the Victorian legislation is not strictly the same as the US legislation since the Victorian State Environment Protection Policy (SEPP) does allow economic considerations. There are various advantages and disadvantages involved with each system but it is clear that, even using the NSW approach, a set of air quality standards is published by the control agency as guidelines which industries should use in preparing an Environmental Impact Statement (EIS). A major advantage of the best practicable means approach is that it allows a rapid updating of such criteria as new information becomes available on air pollution effects and it also allows criteria to be receptor oriented. In fact it is the paucity of knowledge on what criteria should be used (as highlighted in the discussion in Appendix I) that is used to criticise the adoption of air quality criteria in legislation. On the other hand, criticism may also be levelled at the SPCC guidelines and used to weaken air pollution control measures adopted through negotiations between industries and the SPCC or Department of Environment and Planning (DEP), in Commissions of Inquiry, and in the Land and Environment Court. It would appear that one advantage of including air quality criteria in legislation is to avoid the repetition of such objections case by case.

Regardless of which approach is taken, whether it be emission controls or ambient air quality criteria, the EIS prepared for any new development regarding air pollution effects is similar and follows the approach shown in Fig. 46. For example, in the Bayswater power station EIS the final height of the stacks was related to air pollution impact via the use of a Gaussian plume model which simulated atmospheric dispersion of the air pollutant emissions to ground level. Certainly the monitoring networks set up in NSW and Victoria would be similar. Both control agencies monitor ambient air quality levels and also compile information on emissions from industries. Of course the emphasis is different with the SPCC needing emissions information more to check that negotiated agreements are not being broken, whereas in Victoria the Environment Protection Authority (EPA) needs such information in order to draft a plan to control emissions such that ambient air quality objectives are being met. In monitoring ambient air quality levels the SPCC is checking that the emission controls agreed upon are in fact effective in keeping air pollution levels low, while in Victoria the design of the monitoring network is critical in determining whether ambient air quality levels are lower than the adopted standards.

In deciding on the effect of future developments, mathematical models are essential. However, a variety of different models abounds, especially for urban air pollution. In the United States the Environmental Protection Agency (USEPA) has published a set of models which it recommends for use in a variety of different conditions. For example, there are point source models, highway models and urban area models. It probably would be useful if such a list could be compiled by each state control agency and very desirable that one such list be common to all states.

Although there is generally a great deal of similarity between the models used, there are occasions when models do yield quite different results. An example of this is shown in Chapter 4 where a trapping Gaussian plume model yields much higher results than the adopted standard Gaussian plume model. A choice of a model also dictates the data base collected. For instance, although an inversion data set is useful for the operation of a standard Gaussian plume model it is critical when using a trapping model. The differences between the 'worst case' predictions is of the order of a factor of 2 to 3, and this occurs between two models which have the same basic formalism. In Chapter 4 it was shown that an inversion data set is critical in determining the long term effects of both the Bayswater and Liddell power stations as well as the effect of additional power stations.

Whichever form of direct controls is adopted, however, 'economists have, with few exceptions, rejected both direct controls and voluntary compliance, the methods preferred by many others concerned with the environment' (Baumol and Oates 1977). A brief review of the use of economic incentives is now presented in order to compare them with direct controls and to estimate how useful such approaches would be in the Hunter Region. Some economists would argue that the 'best practicable means' approach already recognises this principle given the recognition of political and economic constraints. Some would also argue that air quality criteria are essentially economic and political tradeoffs. However, the theoretical appeal of incentives is that they allow for a more flexible and optimal solution.

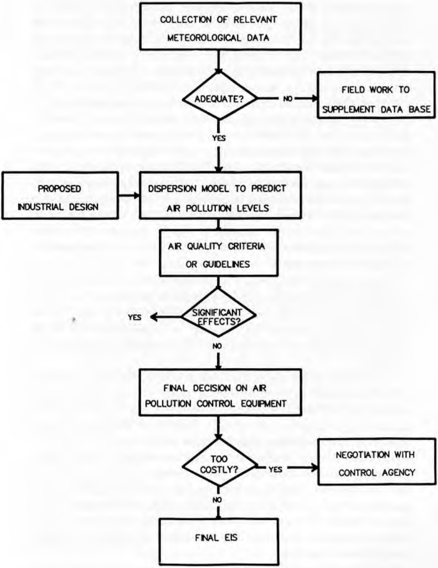


FIGURE 46 The usual EIS approach for air quality impacts

Economic incentives

In general, economists view pollution as an external effect which has to be internalised into the market system with an appropriate costing and pricing approach so that the 'invisible hand' of the price mechanism may operate to arrive at an optimal solution. Of course an economically optimal solution is not necessarily an ecologically optimal solution. Pearce (1976) notes that environmental standards imply some knowledge of benefits and costs yet are not explicitly arrived at in this way. Ferris (1978) has reviewed air pollution standards using toxicological and epidemiological data to arrive at his conclusions (see Appendix I) and in theory this is how standards are set. By implication the standards set a threshold below which the environment (including humans) can assimilate the pollution but above which effects become significant. In principle, therefore, as noted by Pearce (1976), if the standards are indeed the threshold levels then their use, by definition, is the least cost method in pollution control. However, as Morgan *et al* (1983) have shown, there are such wide discrepancies between the results of various toxicologists and epidemiologists concerning damages that it cannot be assumed that the optimal situation exists.

There is a variety of techniques which may be used to implement the appealing policy of charging polluters a price for the damage they inflict on the environment. Baumol and Oates (1977) indicate that for air pollution control these techniques may be broadly classified as (a) emission taxes, (b) emission subsidies, and (c) the auctioning of pollution permits.

Emission charges have been examined as a form of Pigovian taxation which attempts to arrive at an optimal welfare level by setting up an optimal level of costs. As Pearce (1976) points out this assumes that social profit is maximised by setting a tax equal to marginal pollution costs at the optimal output of goods. It also assumes perfect competition which is not the case in practice so only a 'second-best' solution rather than an optimal one is possible. This can lead to problems and Pearce (1976) argues that, if prices are set equal to the marginal product cost plus the marginal cost of externally imposed damage due to pollution, it does not follow that the best social welfare solution has been reached. In fact it is possible that the use of Pigovian taxes may move away from the possible social optimum.

The underlying weakness, as in all economic approaches to air pollution, is the necessity to obtain adequate estimates of the costs and damages of pollution. Given the lack of knowledge regarding the effect of pollution it is clear that such a cost-benefit approach faces severe problems. Certainly all the economic incentives suggested are based on the 'polluter pays' principle which is linked to the concept of equity and the concept of the environment being common property. On the other hand, the weakness of the direct controls approach is that there is no incentive on industries to reduce their emissions further once they have complied with legislation, and setting the same controls for new and old factories is probably not cost-effective.

The problem with the emissions taxing approach is setting the right tax scale. There is little technical difficulty in relating taxes to ambient levels. The present system of direct controls in NSW has already led to the development of mathematical models relating emissions to ambient levels. In fact the monitoring network already established would be adequate in testing the effectiveness of the imposed emission taxes on reducing air quality levels. Therefore the use of emission taxes involves little change to the monitoring and assessment work already carried out by the SPCC.

Baumol and Oates (1977) argue that the *auctioning of pollution permits* is probably better than using emission taxes because such auctioning is more sensitive to inflation and to the demand for industrial expansion. Also it is clear from the results in the Hunter Region that air pollution problems depend on the meteorology of the area considered so that the tax rates may have to be differentially specified for each region. The pollution permit system would simply avoid this problem by selling fewer permits in regions with a greater potential for air pollution. Finally, given the uncertainty in estimating air pollution impacts there is some difficulty in setting a tax rate whereas pollution permits set emission levels directly so the tradeoffs may be recognised as they could for the direct controls approach.

At present the USEPA is experimenting with the use of economic incentives involving the marketing of pollution permits. The policy option of marketing pollution permits has introduced the concept of a 'bubble', which is an imaginary envelope or dome on top of a plant which is required to comply with emission standards as if it has only one stack. In this case, the emission rate of the plant is the sum of the emissions of all parts of the plant. This single-bubble concept can easily be extended to a multi-bubble concept in which the bubble encompasses several plants, the sum total emissions of which do not exceed a given emission standard. Blackman and Baumol (1980), Tietenberg (1980), Lyon (1982), Lakhani (1982) and Noll (1982) have detailed how this approach has been used by the USEPA. At present it appears that the marketing of pollution permits has been applied in a limited way, for instance by offsetting emissions from factories operated by a single company. This policy option has proceeded no further than this because of the problems associated with implementing a market process which achieves competitive equilibrium, has low transaction costs, and avoids source-by-source review. Certainly monopolies have to be avoided in order for the pricing mechanism to achieve the desired cost effective tradeoffs while maintaining air quality standards. However, there are numerous technical problems also associated with the bubble concept itself and these difficulties are discussed in the next section.

James *et al* (1978) believe that pollution rights have a number of problems as 'the victims often are a large, unorganised mass, unable to take actions . . . in general it would be extremely difficult or impossible to create the suitable market conditions to attain the optimal solution'. James *et al* also point out that people may be offended by having to pay for a pure environment if they feel it should be a right and also by governments selling rights to pollute.

However, there are problems with the use of other economic incentives as well. *Emission subsidies* are probably only useful if the polluter is not under the jurisdiction of the control agency such as in the long range pollution problems in Europe and North America. Fortunately in Australia significant interstate air pollution does not appear to occur. However, compensation has already been seen as necessary in some instances such as the effect of coal and other dust from open cut coal mines in the Upper Hunter Region (see Chapter 3).

Given the drawbacks of all forms of economic incentives and direct controls, most economists conclude there is no unambiguous answer to the question of which is best. James *et al* (1978) believe that emission taxes are superior to transferable rights and Pearce (1976) acknowledges the serious problem of monopolies with the latter. Baumol and Oates (1977), however, believe there are some advantages with the use of transferable rights although they conclude that a mix of methods is probably the most desirable approach.

Of course it is desirable to reduce emissions as much as possible and here emission taxes would be a useful incentive. The problem then, however, would be to use some economic method to arrive at a reasonable taxation system. The first step in using economic tools therefore may be to use a method such as cost-benefit analysis to introduce into the negotiations between industry and the control agency the costs and benefits associated with proposed environmental controls. However, even such a preliminary step may require legislation given a recent High Court ruling that the Victorian EPA restrict its considerations only to environmental matters and ignore 'social and economic factors' (for example, Barker 1984). Given this difficulty, the role that economic tools may play in determining the best practicable environmental controls is now briefly examined.

The costs and benefits of air pollution control

It is difficult to dispute the economists' claim that environmental management is inherently economic, involving as it does the wise allocation of scarce resources. However, the Director of the OECD Environment Directorate in 1980 has stated a personal view that, '. . . economic measures can capture only some of the values associated with environmental measures . . . this will always be the case' (MacNeill 1981). Nevertheless it has been shown that most OECD countries spend approximately 0.5-1 per cent of their Gross National Product (GNP) on pollution control equipment (MacNeill 1981). Harris and Ulph (1977) indicate it is higher in Australia. Clearly then some estimate of the benefits associated with various environmental controls is necessary given such expenditure. It may also be important to be able to do this analysis on an industry by industry basis given the disproportionate amount of money some industries pay for control equipment compared to others. For instance MacNeill (1981) has stated that in the United States pollution control investment in 1978 represented 19.5 per cent of total plant and equipment investment in the iron and steel industry compared to 10.5 per cent for the electric utilities. Cordner (1981) has shown that in Australia the percentage of capital costs to industry due to pollution control in 1977 ranges from 7-8 per cent in the textile industry to 23 per cent in the chemicals, petroleum and coal industry.

MacNeill (1981) has summarised the macro-scale effects of pollution control on the economies of OECD countries and stated that such control measures have little impact on unemployment or inflation, and perhaps even on productivity. However, given the disproportionate way in which some controls affect different sectors, there are possibly individual hardships involved in changing employment or upgrading skills.

Measuring the benefits of such environmental protection has not been carried out to any degree in Australia. McColl (1981) has summarised work done in the United States based on the 'willingness to pay' approach for evaluating environmental benefits. The results for air pollution are summarised in Table 67 based on the work of Freeman (1979) in a review for the US Council of Environmental Quality. For comparison the estimated costs of air pollution control are shown in Table 68. McColl indicates that much work needs to be done to improve on most of the techniques used to measure benefits as does Freeman (1979) who also notes that 'where state-of-the-art analyses of the environmental benefits have been undertaken . . . they strongly suggest that environmental protection is good economics'. Certainly Freeman's most reasonable estimate for the USA in 1978 of the benefits due to air pollution control of $21.4 billion is much higher than the costs. However, almost all of these benefits are associated with health effects based on epidemiological studies. Therefore, as McColl states, 'the controversy surrounding epidemiological studies is of major importance'. Most of the health effects measured in this way are due to sulphur dioxide and particulates. For instance, the Californian study of Brookshire *et al* (1979) has shown significant correlations between particulates and the diseases pneumonia and influenza, and between sulphur dioxide and early infant disease. Lave and Seskin (1977) report similar findings.

Using cost-benefit analysis in a project-by-project assessment, a project is generally taken as being in the community's interest if the benefits exceed the costs. If some people are better off and none worse off then there is 'a Pareto improvement' in welfare. However, it is more likely that some are better off and others worse off, and there is a 'potential Pareto improvement' in welfare if, after compensation to the losers by the winners, the winners are still better off. As with all such approaches, value judgments are clearly inherent in the decision-making. There clearly are difficulties in assessing the costs and benefits, identifying the parties involved and differentiating between groups. As James *et al* (1978) indicate, cost-benefit analysis is useful if it is concentrated on areas of analysis where it may be adequately applied, leading to a set of scenarios with which to make a judgment based on relative effects.

However, the work of Freeman (1979) indicates that overall the benefits to air pollution control may outweigh the costs even though this may not be true on a project-by-project basis. Clearly if the economic arguments are to be based on macro-scale effects then the use of cost-benefit analysis on a project-by-project evaluation basis may be unwise. In this case input-output models of structural abatement may be useful.

TABLE 67 Air pollution control benefits in 1978 ($U.S. billion, 1978 prices)

Category	Range	Most reasonable estimate	Pollutants
1. Health—			
stationary sources—			
mortality	2.8-27.8	13.9	SO_2, particulates
morbidity	0.3-11.5	2.9	SO_2, NO_2, particulates
Mobile sources	0- 0.4	0.2	CO, lead, photochemical oxidants
Total health	3.1-39.7	17.0	
2. Soiling and cleaning	0.5- 5.0	2.0	Particulates
3. Vegetation	0.2- 2.4	0.7	Photochemical oxidants
4. Materials	0.5- 1.4	0.9	SO_2, photochemical oxidants
5. Property values	1.1- 8.9	2.7	All (including haze, smoke)
Total*	4.6-51.2	21.4	

* Excludes 30% of property values benefits because of overlap with other categories.
Source: Freeman (1979, Table 1).

TABLE 68 US air pollution abatement and control expenditures, 1972 to 1978

Year	In Actual Prices ($b)	% of GDP	In 1978 Prices ($b)
1972	6.6	1.6	10.9
1973	8.5	1.8	13.2
1974	10.5	1.9	13.9
1975	12.8	2.0	15.6
1976	14.1	2.0	16.2
1977	15.5	2.0	16.6
1978	16.8	2.0	16.8

Source: Rutledge and Trevathan (1980).

James *et al* (1978) have shown that such models can be used to construct scenarios with different structural arrangements, once again to provide options rather than predictions. In this way the relative effect on overall unemployment, productivity and other factors including pollution due to industrial and urban change may be estimated. Clearly the development which minimises a whole range of factors including pollution is preferred. James *et al* (1978) recommend such an approach in environmental management and clearly there are advantages to such an approach. Given that the best practicable means approach to air pollution control in NSW involves setting pollution controls within political and economic constraints such models would clearly be useful in highlighting the consequences of various developmental options.

The High Court ruling restricting the Victorian EPA to environmental considerations and ignoring social and economic factors may restrict the role of the SPCC in NSW in a similar way. However, the Environmental Planning and Assessment Act of 1979 in NSW gives the Department of Environment and Planning the power to regulate environmental planning. Provided the legislation does not preclude the consideration of political and economic factors in its decision-making then the use of economic tools should, in principle, be easily incorporated into the current decision-making process.

Applicability of policy options to air pollution control in the Hunter Region

The air pollutants identified as being of concern in the Hunter Region are listed in Table 69. It has been shown in Chapters 3 to 7 that at present a reasonable assessment of current air pollutant levels in the region is that there appear to be no significant effects due to these levels. However, it has also been noted that some effects still have yet to be adequately measured. For instance, there are few suspended matter data available for the Upper Hunter Region. The sulphur dioxide levels based on less than 2 years of data due to Liddell power station appear to be low enough for a negligible synergistic effect between sulphur dioxide and particulates. However, it is not clear from the meteorological data presented what the future impact of Bayswater power station will be or what the worst case levels due to either Liddell or Bayswater power stations will be. Only the collection of inversion data in the area will clarify this situation. In Newcastle at this stage it is not clear to which air pollutants the acid gas readings refer. More specific monitoring equipment is necessary to obtain a better appreciation of this situation. Also the probability of long range transport from the power stations and aluminium smelters in the area towards Newcastle remains uncertain.

The incomplete nature of the data base in the Hunter Region is quite typical, so the problem of including air pollution effects in a regional environmental plan is not unlike similar problems for other regions.

TABLE 69 Air pollutants of concern in the Hunter Region

Pollutant	Effects	Major sources
SO_2	Health (synergism with particulates)	Upper Hunter power stations
		Lower Hunter power stations
Acid gases	Health	Newcastle industries
Particulates	Health —synergism with SO_2	Open cut coal mines in Upper Hunter
		Newcastle industries
	—lead content	Newcastle industries
	Aesthetic	Open cut coal mines in Upper Hunter
Fluorides	Animal health Damage to vegetation	Aluminium smelters in Lower Hunter
NO_x	Health	Mobile sources throughout the region, especially coal trucks
		Newcastle industry and power stations throughout the region

Therefore any assessment of the applicability of the various policy options to the Hunter Region, as mentioned in the previous sections, should be quite relevant to regional air pollution management in Australia in general.

At present in NSW, air pollution control is based on emission controls with the underlying philosophy being the 'best practicable means' approach. The SPCC publishes ambient air quality criteria to be used as guidelines. An advantage of not having such criteria as standards in legislation allows easy updating of standards as information becomes available. For instance, the 1980 Annual Review of air quality measurements published by the SPCC listed WHO standards for sulphur oxides, suspended particulates, carbon monoxide and photochemical oxidants. However, the 1981 and 1982 Quarterly Air Quality Monitoring Reports published by the SPCC list a combination of WHO, USEPA and NHMRC standards, and include standards for lead, nitrogen dioxide, and non-methane hydrocarbons. Yet this is not a complete list if the standards adopted by other countries are examined. In particular, there is no reference to sulphur dioxide levels for time averages less than 24 hours, which for the Upper Hunter is unfortunate as the most extreme events due to SO_2 emissions from power stations probably occur during the day over time periods of 1-3 hours. For instance, in Mt Isa, Queensland, the smelting operations are closed down if the USEPA 3 hour standard of 50 pphm for SO_2 is in danger of violation and this only occurs during the day. In Chapter 4 it has been shown that there is a range of standards adopted by different countries which varies quite significantly. It would appear then that the flexibility involved in using the 'best practicable means' approach may be bought at the price of uncertainty about which set of standards should be applied and referred to in an EIS.

Certainly the wide range of standards and any review of these (eg Ferris 1978) indicate that there is a great deal of uncertainty about air pollution effects. Nevertheless it is necessary to decide on a set of standards as this then dictates the form of any policy on air pollution control. This can be seen by an examination of Fig. 46 showing the steps involved in preparing an environmental impact statement, which is an essential component of any air pollution control strategy. Central to the preparation of the EIS is the construction of a mathematical model relating emissions and meteorology to ambient air quality levels which in turn are compared with a set of air quality criteria. As stated previously, for a single point source, such as a power station, short time average standards would be most important.

In addition, the model used is also important and Chapter 4 has shown that a more appropriate form of the Gaussian plume model should be used in any EIS for a power station such as Bayswater. Confusion regarding the appropriate form of even the same model is not uncommon and surfaced in the 1983 Commission of Inquiry into open cut mining at Glendell (New South Wales, Commission of Inquiry 1983). The USEPA has recognised this problem and has published a standard set of models to be used in specified instances. Simpson and Hanna (1981) reviewed urban models and found that there was general agreement in categorising models, as shown in Table 70, and also on their performance, shown in Table 71. Models can be categorised into screening models, refined screening models and refined models. Screening models are useful as a first guess of likely effects and, if problems appear likely, more detailed models are used, ending with a variety of refined models which can be used for detailed air pollution impact analysis.

The adoption of a set of ambient air quality standards implies that a set of such models needs to be used. Given that there can be disagreement about the particular form of each model then it is necessary for a standard set of models to be determined as appropriate for a given set of circumstances as the USEPA has done. Otherwise a series of acrimonious debates may occur time and time again between industrial groups and control agencies. There is no 'perfect' model for any air pollution situation just as there is no 'perfect' standard. Nevertheless the choice is critical in determining the data which will be collected for the EIS (see Fig. 46). In Chapter 4 it was shown that the use of an inappropriate model in the Bayswater EIS meant that critical meteorological data (in this case, inversion heights) were not collected.

Of course, if the set of ambient air quality criteria is continually updated so must the set of standard models, which may lead to some uncertainty in industry if an EIS takes some time to prepare. Therefore one advantage of having air quality criteria in legislation is that such updating would be less frequent, given some inertia in the legislative process. However, setting air quality standards too strictly means a loss of flexibility in treating areas differently and losing sensitivity to changing political and economic realities. Any legislation involving ambient air quality criteria should aim to avoid such problems.

Only by retaining such flexibility may economic tools be used in air pollution management. However, like the use of epidemiological tools and mathematical models for air pollution dispersion, care needs to be taken in the choice of methods. For instance, it was clear in the last section there was some danger in applying cost-benefit analyses to air pollution control on an industry-by-industry basis. In the Upper Hunter it would be inappropriate to apply a cost-benefit analysis just to pollution control measures on the power stations of the NSW Electricity Commission. As shown by McColl (1981), most of the benefits of air pollution control are health benefits and it is recognised that SO_2 and particulates act synergistically. Therefore the effect of coal dust from open cut coal mines as well as controls on particulate emissions and SO_2 from the power stations need to be examined. Since not all the open cut coal mines in the area are owned by the NSW Electricity Commission the economic analysis would need to be extended to include both the coal mining industry and the electric power industry in the area.

However, the electric power industry is also linked to the iron and steel, aluminium, and other industries in and around Newcastle so that these industries would also be involved in an economic analysis of the

TABLE 70 Different model types

Generic model type	Number of sources	Area types
Refined Usage		
Grid		
(a) Region oriented	Multiple-source	Urban Rural
(b) Specific source oriented	Single-source	Rural
Trajectory		
(a) Region oriented	Multiple-source	Urban
(b) Specific source oriented	Single-source	Urban Rural
Gaussian		
(a) Long-term averaging	Multiple-source Single-source	Urban Rural
(b) Short-term averaging	Multiple-source Single-source	Urban Rural
Refined/Screening Usage		
Isopleth	Multiple-source	Urban
Screening Usage		
Rollback	Multiple-source Single-source	Urban
Box	Multiple-source	Urban

---

* Only if NO_2 is taken to be total NO_x.

Upper Hunter. In Newcastle itself of course, the acid gas concentrations and dust levels are due to a variety of industries. The controls on particulate and SO_2 emissions of the power stations around Lake Macquarie are probably the only major factor in considering air pollution levels in that area but the demand for power from industry in the Hunter Region and elsewhere provides an economic link to the rest of the region. Therefore the Leontief input-output models suggested by James *et al* (1983) emphasising energy sectors and energy developments in the

llutants	Terrain complexity	Required resolution
, HC, CO, NO_2 hour), SO_2 and 24 hour), TSP	Simple Complex	Temporal Spatial
, HC, CO, NO_2 hour), SO_2 and 24 hour), TSP	Simple Complex	Temporal
, HC, CO, NO_2 hour), SO_2 and 24 hour), TSP	Simple	Temporal Spatial (Limited)
, HC, CO, NO_2 hour), SO_2 and 24 hour)	Simple Complex (Limited)	Temporal Spatial (Limited)
$_2$ (Annual), TSP, $_2$ (Annual)*	Simple	Temporal
$_2$ (3 and 24 ur). CO, TSP, $_2$, (1 hour)*	Simple Complex (Limited)	Temporal Spatial
, HC, NO_2 hour)	Simple	Temporal (Limited)
, HC, NO_2 $_2$, CO, TSP	Simple	—
, HC, CO, NO_2 hour), SO_2 and 24 hour), TSP	Simple Complex (Limited)	Temporal

Australian economy linked to the black coal reserves of the Hunter Region would seem to be an appropriate economic tool. In this way a whole range of politically and economically realistic scenarios for development in the region can be assessed on a variety of grounds including unemployment, economic growth and environmental effects.

The present legislation in NSW, namely the Environmental Planning and Assessment Act 1979, by recognising three tiers of planning—state, regional and local—provides an adequate framework for the inclusion of

TABLE 71 Performance measures that can be calculated by each model type (Simpson and Hanna 1981)

Model	Performance Measure Type			
	Peak	Station	Area	Exposure/ Dosage
Refined usage				
Grid				
Region oriented	X	X	X	X
Specific source oriented	X	X	X	X
Trajectory				
Region oriented	X	X		
Specific source oriented	X	X	X	X
Gaussian				
Long-term averaging	X	X	X	
Short-term averaging	X	X	X	X
Refined/screening usage				
Isopleth	X			
Screening usage				
Rollback	X			
Box	X			

such a model at the regional and, if necessary, state level. It remains to be seen, however, if the legislation is designed in such a way that environmental planning allows the consideration of social and economic factors or whether, as in Victoria with the EPA, the legislation draws a legal dividing line between 'environmental considerations' and 'social and economic factors' as happened in the High Court decision referenced by Bates (1983). If this latter situation is possible then the legislation needs to be rapidly amended to enable the inclusion of such a model, as that suggested by James *et al* (1983), into the planning process.

Solutions based on mixed policy instruments

Previous sections suggested that the present clean air legislation using direct controls could be improved by the careful inclusion of standards on ambient air quality criteria with an attendant set of standard air pollution models. However, can such legislation be further improved by the inclusion of economic incentives? In this chapter it has been concluded that only two forms of such incentives seemed potentially appropriate—emission taxes and auctioning of emission permits.

Jakeman (1985b) concluded that the approach to environmental quality control in Australia should involve an integration of policies since no single policy instrument, neither regulation nor fiscal incentives, is suitable for all pollution problems. He also argued that control mechanisms need be evolutionary. Initially they can be based largely upon the present system with integration of incentive mechanisms into the current regulatory framework, as is emissions trading in the United States, for example. This enhances the political and institutional appeal of new instruments while at the same time facilitating change. Jakeman also saw other advantages in this mixed approach, especially in the way the technical difficulties associated with optimal fiscal incentives can be overcome. He argued that optimal control efficiency can rarely be achieved and that the benefits (technological innovation and increased efficiency) to be gained from suitable non-optimal policies are well worth having.

A brief summary is now presented of the technical difficulties associated with implementing optimal fiscal incentive policies for the control of pollution. Then second best policies are specified which could either be directly implemented, or investigated further, for environmental problems in the Hunter Region.

Technical difficulties

First, continuous source monitoring technology may be unavailable or too expensive. This creates problems for a dependable system of pollution fees unless surrogates can be measured. Second, environmental modelling for transport of discharged pollutants to receptor sites is subject to some uncertainty. Too much uncertainty here results in poor inputs for the estimation of impacts from dose-damage functions and requires that more spatially intensive ambient monitoring be performed to directly observe the transport of emissions; makes difficult the inference of individual source contributions and decreases the ability to predict future impacts with a useful confidence; and creates problems for the allocation of a quota of pollution permits even when based upon ambient environmental quality guidelines rather than actual damages. Third, dose-damage information is unreliable and creates problems for designing an optimal fee system and for allocating optimal pollution quotas in a market system. Fourth, economic costs of damage are usually uncertain; and create problems for scheduling the optimal charges in a fee system. Fifth, economic costs of abatement may be uncertain; and create problems for scheduling the optimal charges in a fee system.

For a huge majority of air quality problems, the status of damage information is poor, and this is probably going to be the case for some time. Consequently it is recommended that pollution control be exercised to achieve ambient environmental quality standards or guidelines where the information on threshold levels for receptor damage is known with some certainty. The term 'guidelines' is preferred because it suggests, as stressed earlier, that the choice of criteria be site-specific and take into account the relevant environmental assimilative capacity. While the maintenance of ambient environmental quality objectives for any control approach does not lead to optimal efficiency it is important to recognise that many of the desirable properties of an incentive approach do not require equating (marginal) costs and benefits but arise from the imposition of a sliding scale of punishment (payment of fees or the purchase of additional quotas) for increases in pollution.

Continuous monitoring technology for air pollution emissions will become increasingly available and less expensive (Court and Wilcox 1984) but at present is only economically viable where the scale of the operation is large. This rules out a great deal of the potential for imposing a truly effective system of fees unless easy-to-measure surrogate variables can be used to estimate emissions adequately.

The status of modelling differs markedly according to pollutant and source type. It is extremely difficult to predict long term ambient concentrations of photochemical oxidants, hydrocarbons and nitrogen oxides and so there is a great deal of uncertainty about how effective various control measures will be in quantitative terms. On the other hand, the prediction of less reactive pollutants from area and point sources is more straightforward. Methods are also becoming available now to incorporate the effects of long-term meteorological change on the full frequency distribution of air pollution concentrations. This allows for the possibility of specifying the number of quotas for pollution markets and of investigating the effects of emission trades including bubbles, offsets and banking.

The major individual air quality problems of the Hunter Region are now considered and ways of circumventing the mentioned limitations are suggested, beginning with acid gas and particulate pollution in the Newcastle airshed.

Acid gas and particulate pollution in Newcastle

It has been shown in Chapter 5 that it is possible to predict both long-term averages and extreme concentrations of non-reactive and minimally reactive pollutants from a number of sources according to meteorological information and emission input estimates. The work of Chapter 5 on the Newcastle airshed has been carried out to predict, for a range of emission strengths and the full history of available meteorological years, the average annual concentrations and annual maximum concentrations from 24 hour recordings of acid gases (mainly composed of sulphur oxides and nitrogen oxides) and for particulates. In this way, environmental air quality 'standards' can be compared with the average concentration and the 24 hour maximum for the worst meteorological year, corresponding to poor dispersion conditions, using current emission strengths. Of course, the modelling can provide a plethora of information. One can categorise annual meteorological regimes, for example into poorly dispersive, fair and strongly dispersive; tabulate their frequency of occurrence from the meteorological history; and calculate for each type of year the increase (or decrease) in current emission strength required to violate chosen ambient air quality criteria. Clearly, this type of information can be used to evaluate the assimilative capacity of an airshed. The Newcastle predictions are deemed to be accurate within a factor of two.

The relevance of being able to model such an airshed to this accuracy is that it provides the basic requirements for investigating the feasibility of introducing pollution quotas. Despite the availability of only a relatively short period of pollution monitoring, longer histories of meteorology can be used with appropriate models to evaluate maximum desirable emission strengths with a chosen margin of safety. In combination with emission source locations, emission strengths, pollution abatement costs and chosen environmental assimilative capacity, marketable pollution permit activity could be simulated to judge the feasibility of such an approach.

The major attraction of a sufficiently competitive and equitable permit system is that it could be accommodated within the current direct regulatory framework but at the same time provide incentives to industry to minimise pollution levels. The expensive continuous monitoring requirements of a tax system are avoided. Trades and indeed other activities such as bubbles, offsets and banking can take place with suitably stringent compliance monitoring for a period before and after the activity change.

There would appear to be some virtue in offsetting emissions coming from one industry, for example steelworks. At present, the air pollution effect of such a conglomeration of factory stack emissions is mathematically modelled by assigning an average emission factor to grid squares usually about 2-5 km square (eg the ATDL model). Given this method of estimating air pollution effects, the most-cost-effective set of controls on the stacks in the factory complex which maintained the average emission rate would then be used. In this way offsetting has proceeded in the USA. In this sense, a 'bubble' covering a 2-5 km square grid, say, fits current modelling methodology. However, the 'multi-bubble' concept involving larger areas over which offsetting takes place faces severe problems.

The variation in acid gas levels experienced at different receptor sites in Newcastle highlights the sensitivity of recorded air pollution levels to the spatial distribution of air pollution emissions. For instance, it is possible to plan numerous spatial distributions of emission sources of varying strength which yield the same total for emissions in Newcastle but the spatial distribution and intensity of the 'hot spots' would vary markedly with each choice of spatial distribution. In general, it would still be necessary to allow as little concentration of high emissions as possible in order to avoid such problems. Therefore a 'multi-bubble' concept or a pollution quota system would need to be treated with caution.

Emissions trading may not be feasible across areas separated by more than a few kilometres. Certainly if there is any significant effect in Newcastle due to long range transport from the power stations in the Upper Hunter Region or in the Lake Macquarie area, the offsetting procedure within a bubble in Newcastle is invalidated.

The use of pollution taxes for some industries, particularly smaller emitters, may also be integrated rather easily within the present direct command and control system. Polluting premises could have their licences graded on a regular basis according to emission categories chosen by the State Pollution Control Commission. This would provide an incentive for industries to attempt further control in order to achieve a lower emission category. The SPCC is at present investigating the details of a staged licensing system (Wilcox 1984).

Dustfall from coal-mining activity

The problems associated with the modelling of dustfall from open cut coal mining, additional to those normally encountered with inert pollutants, have already been noted in Chapter 3. Briefly, they can be summarised as follows. First, there are a number of poorly quantifiable emission sources and source-types to be considered which are close to ground level. For example point sources are blasting, overburden and coal removal; line sources are those resulting from trucking activity; and area sources constitute bare areas exposed to wind. Second, allowance must be made for particle fallout and this varies in a complex fashion with distance from the mine, size distribution of the dust particles and wind speed and direction. Third, the scale of behaviour is small with most fallout occurring within 1-2 kilometres. Therefore ground level sources make micro-meteorological effects and even minor topographical features important. Fourth, monitored data tends to be collected only about once a month so that it takes a few years to obtain a data series long enough for modelling.

Consequently, models used to date in the Hunter Valley, have been borrowed from overseas where there has been more experience with a dustfall problem and they have been deterministic in character but have been adjusted somewhat for Australian conditions. However, over the next few years as the data base grows the opportunity exists for modelling on a more probabilistic basis. Understandably, there is presently some disagreement between results obtained by the deterministic models although a number of users are now getting reasonable agreement for long-term annual averages with data monitored. Jakeman and Simpson (1983) have outlined the monitoring requirements and methodology of a hybrid dust modelling approach. It involves sensitivity analysis of the best deterministic models to improve their predictive reliability for long-term mean values and incorporation of a statistical component to predict variations from the mean and extreme events under different natural meteorological regimes.

In summary, there is a good prospect for dust impacts that there will soon be models, especially once further data are available to refine them, which will be useful enough for planning purposes, such as to determine the approximate extent of buffer zones in advance. On the other hand, they are not accurate enough, at least at present, to be useful for the prediction of short-term levels in general and of impacts on specific residences.

Fortunately, such a level of precision is not necessary at present since an incentive scheme is already operating to control the impacts of open cut coal mining in a potentially efficient manner. This scheme relies less on modelling than on monitored data at receptor sites. Residents in the vicinity of mining leases are entitled to compensation when they experience dustfall levels above a threshold value. This has the effect of a company applying controls such as watering, chemical spraying, blasts timed for the most favourable winds and so on, only to the extent that it is less expensive than compensating affected residents.

The number of residences or at least the area impinged upon is usually quite small so that direct monitoring of locations of interest can be achieved at low cost. For dustfall, instrumentation currently consists of a simple funneled jar whose contents are weighed and analysed once a month.

Of course the efficiency of this approach hinges upon two important requirements: the dustfall level at which disamenity is incurred, and satisfactory compensation measures. To determine the former, the perception or attitude survey was carried out for communities on the fringes of open cut coal mining leases and this has been summarised in Chapter 3. Basically, the results tend to confirm the SPCC's criteria estimated on the basis of complaints and overseas evidence that at levels as low as 4 grams per square metre per month disamenity can be incurred and at 10 grams the annoyance is severe.

With respect to the level of compensation, the present situation is unclear since only broad guidelines have been specified. However, Court and Wilcox (1984) have proposed a sliding scale scheme with the loss of amenity being determined from dustfall levels suffered and average decrease in property prices. They cite possible problems as apportioning the blame when there is more than one operation in the area and the potential for abuse of the monitoring system. However, they see modelling as an aid here to check these cases and the use of penalties for both mining operators and residents influencing gauged recordings. The use of directional gauges would also go a long way to sorting out the first problem. From an administrative viewpoint, Court and Wilcox (1984) regard the calculation of annual compensation payments on the basis of actual rather than predicted pollution as not requiring significantly more resources and that the extra administrative burden would be considerably counter-balanced by the reduced need for ensuring the continuing compliance of control measures at mine sites.

The proposal can be summarised in terms of effectiveness criteria specified by Baumol and Oates (1977). It has dependability, incentives for maximum effort, economy and minimal interference. These hold because it is basically an incentive taxing system. Additionally, it satisfies their adaptability to economic growth criteria because taxes are based on property prices and it would have reasonable political appeal because it is based fundamentally on the current system where compensation has already been established as a requirement, albeit defined somewhat loosely. Such a system could be achieved without significant advances in modelling accuracy since impacts can be measured directly. However, improvements in the modelling area would be useful for planning purposes.

Pollutants from large point sources in the Hunter Region

The point sources considered here include thermal power stations and heavy industries such as smelters and steelworks. The pollutants of major concern from these sources tend to be sulphur dioxide, nitrogen oxides and particulates. Lead and fluorides can also be a problem from smelters but they have particular features which warrant leaving additional discussion on them until later in the section.

Ambient concentrations of sulphur dioxide, nitrogen oxides and particulates from elevated point sources can be predicted from emissions with reasonable accuracy—the often quoted factor of 2 accuracy is relevant in this case especially for sulphur dioxide and particulates (Jakeman *et al* 1985). Therefore it is possible with reasonable meteorological information to determine the levels of emissions which do not lead to exceedance of assimilative capacity in a region at least in terms of ambient air quality 'standards'. The review of dose-damage threshold information for various pollutants in Appendix I concluded that the USEPA primary and secondary standards for sulphur dioxide and particulates provide adequate safety for the protection of human health and damage to vegetation and materials. Again, assimilative capacity should take into account the possible variations in meteorology, especially those not used in validating the model(s) to be used. Clearly, for a given level of emissions there may be infrequent meteorological conditions which lead to the highest levels of pollution and there needs to be an evaluation of how often extremes above the ambient standards could be tolerated.

The main point is that it is possible, with adequate meteorological data, to decide upon the maximum emission strengths which conform to the arbitrarily chosen assimilative capacity. This leaves the way open to charge emission fees on the basis of pollution abatement costs or alternatively to assign pollution quotas. However, the former will tend to be the more practical incentive since most large point sources in the Hunter Region operate in isolation from other substantially polluting industry. When they do impinge they are often operated by the same authority as is the case with power stations. In such cases, it may make sense to allow for emission bubbles and banking which can be implemented within the present administrative framework.

The option of emissions fees for isolated point sources leads to the question of appropriate emissions monitoring. Tax on fuel used or its sulphur content would not seem to provide sufficient incentive to generally improve housekeeping such as regular changing of bag filters to collect the designed proportion of particulate emissions. For large scale operations where returns are high, continuous emissions monitoring is becoming a viable option. The capital cost for two 350 MW units of a power plant in New Mexico was $224,500 with up to 3 staff required for maintenance (Taylor 1982). However, two points can be made here. Now that there is a direct need for such technology, particularly in the United States, the costs are likely to fall dramatically in the coming years. Second, many of Australia's isolated point sources are producing ambient sulphur, nitrogen oxides and particulate pollution below the thresholds of environmental standards so that there is in many cases some lead time before the stresses of economic growth will change this situation markedly. Clearly, one industry in which growth is likely to occur is the thermal power industry. Presently there is no wet scrubbing to reduce sulphurous emissions since Australian coals have been sufficiently low in sulphur.

It may make sense, however, to introduce continuous emissions monitoring when it is predicted that airsheds will become sufficiently saturated with sulphur dioxide for new power sources to have scrubbing technology. This may be likely to happen when the next generation of power sources are built in the Hunter Valley. The charge of a suitable fee would then provide incentive for efficient operation of that technology. The fee could be based upon present knowledge of abatement costs for which there is reasonable information (Australian Environment Council 1983a,b,c).

In concluding this section, an extended discussion on the particular problems of lead and fluoride emitted from point sources is warranted. While the point sources of lead are mainly smelters, fluorides can be emitted by a number of industries. In the Hunter Region these include aluminium smelters, steelworks, brickworks, thermal power stations, glassworks and fertiliser industries. Both pollutants have two features in common. They are more difficult to model than the other pollutants considered earlier in this subsection though not just because of their different reactivity. Lead can be discharged in many forms and as a particulate it falls out in a complex manner, while fluorides are mainly emitted at low level. The second feature is a consequence of these properties, namely that impacts, at least the important ones, tend to be localised.

It is difficult therefore to be confident of ambient concentrations and hence the precise impacts before such an industry is in operation. Of course, absolute upper bounds to the likely level of pollution can be ascribed from other sites of similar activity. A fee for emissions could be charged based upon abatement costs. However, the authors are unaware of any continuous emissions monitoring being undertaken for lead and fluoride. Of course surrogate measures could be used for example by calculating mass balances for fluoride. However, their use is questionable. Because of the major localised effect of these pollutants it would not be too administratively complex to charge or pay compensation on the basis of monitored ambient concentrations and the value of the property impinged, as has been recommended by Court and Wilcox (1984), especially for dustfall from coal mining activity. The two aluminium smelters in NSW already operate large ambient and other data collection networks. The Sulphide Corporation at Boolaroo also has its ambient lead levels measured in the vicinity. Such a taxing scheme based upon ambient rather than source pollution may be more equitable for receptors and polluters when precise impacts are less certain before plant operation.

Conclusions

It would appear that there are several policy options which should be considered in air pollution management in NSW:

- The incorporation of economic input-output models into regional and state environmental planning in order to better understand the impact of development on a range of issues, such as employment as well as environmental degradation.
- The use of offsetting for more cost-effective air pollution control for factory complexes of area roughly less than 2.5 km square.
- A consideration of the use of emission taxes as an incentive to reduce air pollution emissions. These may be based on:
  the gradation of pollution licences for small emitters,
  the continuous monitoring of source emissions from large isolated point sources, if warranted in the future, and
  ambient monitoring of lead, fluorides and dustfall where modelling is difficult and effects are localised.
- Simulation of the pollution market and hence its competitiveness for industry in the Newcastle airshed with a view to introducing pollution quotas. While the establishment of an effective pollution market may have problems, the research costs for investigation of this possibility are low.

[illegible] However, [illegible] [illegible] and pollutants when [illegible]

Conclusions

It would appear that there are several policy options which should be considered in any pollution management in NSW:

- The incorporation of economic input-output models and regional and [illegible] environmental planning [illegible] in order to better understand the impact of development on a range of sectors, such as [illegible] as well as environmental degradation.
- The use of [illegible] pollution control [illegible]
- [illegible]

SECTION IV

Conclusions and recommendations

9

Conclusions

The conclusions from the CRES study are presented in two separate sections. The first presents our findings about the specific air pollution problems of the Hunter Region both currently experienced and expected under future development scenarios. The second section deals with conclusions based upon methodology and these have general implications for the performance of regional assessments of air quality risks. Clearly there are some uncertainties which make positive conclusions quite difficult and where it is important to be more definitive, recommendations have been made, especially with regard to monitoring and modelling, in Chapter 10 to improve the state of knowledge.

Air quality conclusions

The pollutant emissions of major concern in the Hunter Region are sulphur dioxide and (suspended and deposited) particulates. There is also a strong possibility that emissions of nitrogen oxides are a significant contributor to air pollution in the region. The latter have not been measured. Before amplifying further, it is important to provide some background on the cumulative effects of these three pollutants.

In general, the combined effect of sulphur dioxide and airborne or suspended particulates on public health and welfare are considered worse than some of their individual effects. The major reason for this is that particulates can act as carriers of gaseous sulphur dioxide, effecting deposition into the lungs and on materials, for example. In fact, ambient air quality standards are prescribed with knowledge of such synergism and in many cases the standards for sulphur dioxide must be considered in conjunction with the standard(s) for particulates. Consequently, ambient sulphur dioxide concentrations, which are near to violating environmental standards of the United States for instance, may not constitute a significant risk if accompanying concentrations of total suspended particulates are well below the relevant environmental standard.

Like sulphur dioxide, oxides of nitrogen are also acid gases and it must be considered that there is potential for these gases, particularly nitrogen dioxide, to have synergistic effects in combination with particulates. The World Health Organisation consequently specifies its recommended goals for acid gas levels in conjunction with suspended matter.

While sulphur dioxide, nitrogen oxides and particulates occur individually in high concentrations in parts of the Hunter Region, nowhere have they been measured jointly in such concentrations as to present a significant air quality risk. Indeed, the CRES analysis indicates that the present annual average levels of sulphur dioxide with particulates, acid gases with particulates, and nitrogen dioxide alone, are probably low enough throughout the Hunter Region that there should not be any detectable adverse effect from these pollutant combinations on the population in the long-term. This is not to deny the possibility that future research and analysis of epidemiological data in particular may reveal conclusively that the morbidity of populations is singularly and significantly affected by even low levels of pollutants.

It is quite likely however, that short-term levels of these three pollutants are sufficiently high as to represent a level of concern from time to time. For example, the violation of the United States Environmental Protection Agency's short-term primary standards may present a level of discomfort to the more susceptible members of our population such as those with bronchial complaints. Violation of the National Health and Medical Research Council's short-term goal for nitrogen dioxide may cause some hyperactivity in asthmatics.

The Upper Hunter Region

The major air quality effect of which we are aware in the Hunter Region is the loss of amenity incurred by populations suffering dust fallout on the fringes of open cut coal mining activity. The areas most affected have been Ravensworth and Maison Dieu and the major problems are dust and noise. More recently the NSW SPCC (1983) has reported that sites around Warkworth also have exceeded the Commission's interim criterion for dustfall of 4 g/m^2/month (annual average) which is a level thought to be inconsistent with the current amenity of the affected areas. The criterion is based upon standards applied in a number of American states and experience of the dustfall level at which the SPCC has received complaints. The SPCC also regards 10 g/m^2/month (annual average) as an unacceptable level. Our perception-attitude survey supports the interim criterion adopted by the commission but there is a possibility that a significant loss of amenity could occur at a slightly lower level than 4 g/m^2/month. On the other hand, amenity loss is not likely to be significant below 2 g/m^2/month since the attitudes and perceptions of surveyed populations enduring this level were about the same as a control population subjected to normal rural background levels.

Environmental effects near coal mining areas are considered to be primarily of a nuisance value by 40 to 60 per cent of residents depending upon locations. However, a significant proportion of residents surveyed feel that they incur some hardship such as the need to do extra cleaning. On the other hand, the majority of residents (87.5%) in the worst affected area rate their location no less highly compared to previous places of residence.

The survey analysis also reveals that there seem to be no significant differences in health problems between the mining and non-mining regions surveyed. In particular, there are no significant differences in the occurrence of bronchial problems for different dustfall levels.

Our analysis of air pollutant concentrations in the Upper Hunter Region reveals four important points:

- annual average levels of sulphur dioxide are lower than recognised standards which protect long-term public health, vegetation yields and material damage;
- only the more conservative short-term health standards (1 hour to 24 hour averages) of some countries for sulphur dioxide are in danger of violation a few times per year at locations towards the north-west and south-east of Liddell power station;
- the National Health and Medical Research Council's maximum permissible level for suspended particulates and the United States Environmental Protection Agency's National Ambient Air Quality Standards for total suspended particulates are in danger of violation from time to time around the Ravensworth area; and
- estimated levels of fluorides and particulates emitted from the power station are not a cause for concern at present.

The short-term standards for sulphur dioxide protect both sensitive vegetation from injury, especially cultivated crops, and the more susceptible members of the population from such effects as increased frequency of asthma attack and increased respiratory problems for chronic bronchial patients. On the positive side it should be recognised, that these standards are intended to provide a margin of safety for the majority of the population; that the maximum levels do not occur in the larger populated areas; that Australian native vegetation generally can be assumed to be less sensitive to airborne pollutants than cultivated crops; and finally that the sulphur dioxide standards should be applied in conjunction with suspended particulate standards. The consequence of the last condition is that only in the Ravensworth area do high levels of particulates and sulphur dioxide concentrations combine to present a potentially significant health risk.

On the negative side, our analysis and modelling shows that there is a strong possibility that short-term nitrogen oxide levels could also be of concern in the same locations at which the sulphur dioxide maxima occur, and that there is some uncertainty about the degree to which meteorological conditions in combination with the topography of the Valley can induce trapping of pollutants and thereby increase ground level concentrations significantly. Nitrogen oxides and sulphur dioxide are both acid gases and it is likely that their combined effects will at least be additive. An analysis of Williamtown subsidence inversion data suggests that inversions below 1000 m leading to increased concentrations may occur up to 40 times per year in the morning in the Upper Hunter Region and up to 10 times per year in the afternoon.

The air quality assessment in the Upper Hunter Region also looked at the potential impacts of future development. The siting of the new Bayswater power station, for example, appears a good choice on air quality grounds. The maximum pollutant levels to be expected solely from this source are a little higher than those from the nearby Liddell power station. However the maxima from the two stations will generally be produced at slightly different locations. The two power station plumes may combine, but the combination will only occur about 1 to 2 days per year when dispersive conditions are poor.

The air quality effects for up to three additional power stations were also considered; at Whites Creek, Upper Saddlers Creek and Ponds Creek which were mentioned in the Bayswater Environmental Impact Statement as possible future sites. The CRES analysis indicates that with the addition of any of these power stations the maximum levels will not increase beyond that of the combined effect of Liddell and Bayswater but levels in general will rise. The two sites at Upper Saddlers Creek and Ponds Creek are preferred on air pollution grounds to that at Whites Creek as fewer people will be affected by the increased pollution. Of these two sites, Ponds Creek is preferred as the high levels should occur less frequently.

The Newcastle area

Air pollution problems in the Newcastle area are due to high acid gas concentrations (which basically would include sulphur and nitrogen oxides), and particulate levels. Ozone levels are sometimes high and there is also a lead problem at Boolaroo which seems due more to industrial pollution than motor vehicle pollution. We deal with these in reverse order.

It is highly likely that the NHMRC and USEPA standards adopted as guidelines by the SPCC for lead particulates has been violated. The guideline is 1.5 micrograms per cubic metre for a 90 day average whereas measurements are reported as annual means and these have ranged up to 4 micrograms per cubic metre. While the literature on the effects of various levels of lead intake on human health is confusing, it does seem that the adopted guideline provides a reasonable margin of safety. On the other hand, if ambient lead concentrations are continually above 5 micrograms per cubic metre then children run the risk of acute lead toxicity.

Ozone measurements are taken only at Adamstown. While short-term (1 hour to 3 hour average) air quality standards for this pollutant are violated by a small margin at times, it would appear that there is little threat of damage to vegetation and materials in the urban area and that there is some risk of problems such as nose, throat and eye irritation on the occasions that the very high levels occur.

Total suspended particulates are also only monitored at one station, Boolaroo. The levels there indicate that the SPCC's adopted guidelines are often violated. On the other hand, measurements of suspended matter at other locations are well below the SPCC's adopted criteria and suggest that ambient dust is not a general problem throughout Newcastle. Annual average levels of dust deposition are reasonably high, however, fluctuating around the 4 grams per square metre per month figure adopted by the SPCC as an interim criterion for yielding a loss of amenity.

Both annual mean levels and short-term acid gas levels have been quite high but suspended matter readings are low enough to indicate a low risk to public health from the combination of these two pollutant types. With respect to the air quality implications of any new development, the CRES modelling suggests that a low risk strategy would be to avoid any significant increase in acid gas emissions above present levels while a doubling of emissions leading to suspended particulates could be tolerated. Natural gas with its lower sulphur content has started to replace oil burning as an industrial energy source. If this substitution becomes substantial, then it should not be difficult to maintain such a strategy.

The Lower Hunter Region

There are two potential air pollution problems in the Lower Hunter Region outside of Newcastle: from sulphur dioxide and fluoride. The major emissions of sulphur dioxide are from the coal-fired power stations in the south-east and the two aluminium smelters at Kurri Kurri and Tomago. The major fluoride emissions emanate from the above two aluminium smelters. Modelling results by James *et al* (1983) suggest that annual average sulphur dioxide levels should be quite low but short-term levels may exceed the more conservative air quality standards of some countries. On this basis, short-term nitrogen oxide levels may be of concern as is speculated for the Upper Hunter Region. However both acid gases may be of sufficiently low ambient concentration at Boolaroo, which is perhaps the only location where suspended particulates are high, that the health risk from pollutant combinations is quite low. Because of the poor data base any new acid-gas-producing development in the Lower Hunter Region should be preceded by appropriate monitoring and modelling exercises.

Analysis of fluoride data in the vicinity of the two aluminium smelters and the results of modelling by James *et al* (1983) indicate that the fluoride problem is basically in check at the moment. There are some high levels in forage, vegetation and in the atmosphere in the close vicinity of the smelter, say less than a 5 kilometre radius. Outside the close vicinity of smelters, however, ambient levels of 0.1 micrograms per cubic metre and fluorine leaf content of 25 to 30 micrograms per gram, adopted as conservative benchmarks by the State Pollution Control Commission, are not being violated on an annual basis. However these levels have been exceeded for the smelter at Kurri Kurri on a monthly basis which indicates that there is some chance of damage if a sufficient number of consecutive high pollution months are encountered in a growing season.

At present, emission levels of the fully operational smelter at Tomago are sufficiently low to indicate some cause for optimism about future fluoride levels. Emissions at the Kurri Kurri plant have just been increased over very recent levels with the commissioning of a third production line in mid 1985. It is not expected, however, that total emissions will be higher than 1983–84 levels. This needs to be confirmed after a reasonable operating period since any large increase in emissions would exacerbate ambient levels and significantly increase the risk of damage to sensitive vegetation species. Certainly any new development proposals which increase the present load of fluoride emissions in the vicinity of Kurri Kurri, as probably would have occurred if the Lochinvar smelter had gone ahead, should almost categorically be rejected. Given the state of the world aluminum industry with demand for its products below expectations of a few years ago, any new smelter development appears unlikely before 1990.

Mobile sources of pollution

The contribution of mobile sources to pollution levels in the Hunter Region is largely unknown since little specific monitoring of related ambient concentrations has been carried out. A modelling exercise was therefore undertaken by CRES to simulate pollution levels in major towns subjected to traffic from coal-related and other heavy-duty transport. Singleton, Maitland and Muswellbrook were chosen as towns worthy of investigation. It should be realised that clearly there is a number of uncertainties affecting the results.

Bearing this in mind, the results are:

- nitrogen oxides and carbon monoxide are the pollutants most likely to be of concern in the future;
- maximum pollutant levels are likely to appear in the morning peak period between 6 am and 9 am while the afternoon peak at around 4 pm is expected to be lower due to increased dispersion from much higher wind speeds;
- Maitland would be the worst affected of the three towns;
- assuming an increase in traffic volumes of 4.5 per cent per annum, by the year 2000 carbon monoxide concentrations are likely to remain below ambient air quality standards while nitrogen dioxide levels may then exceed at least some air quality standards in the three towns;
- the application of nitrogen oxide emission controls on heavy-duty vehicles could significantly decrease expected levels; presently no control for nitrogen oxides is required for heavy-duty vehicles in Australia; application of the levels set for the state of California in 1981 for heavy-duty vehicles would yield about a 20 per cent reduction in expected levels; another reduction of about 20 per cent could be obtained if additional controls were placed on motor cars at the level set nationally in the United States in 1981.

There are long-term proposals to build by-passes for these three towns. If they were to go ahead in the early 1990s then there appears little cause for concern about the effects of pollution emission from motor vehicles in the major through-traffic towns of the Hunter Region.

General conclusions on methodology

The methodologies adopted in this assessment of the air quality effects of resource development in the Hunter Region have been based upon the concept of risk or the probability of occurrence of a hazardous event. This is consistent with the increasing acceptance that the uncertainty associated with the description of environmental systems requires the prediction of events in probabilistic terms. And in the case of air pollution the relevant probabilities to consider are those related to the calculation of environmental damages. However, the pollutants of concern in the Hunter Region have not generally reached damage thresholds. Therefore the upper percentiles of pollution concentration should be examined to determine the safety margin between levels experienced, or likely to be experienced, and those threshold levels which cause damage. Such a comparison is best made on an annual basis because most air quality standards are prescribed for calendar years and a one year period will also include many of the effects of different seasonal fluctuations in meteorology.

Statistical models and hybrid (deterministic/statistical) models were developed as responses to these requirements. The hybrid area source model was particularly successful. It allowed the prediction of acid gas concentration distributions in the Newcastle airshed from rather simple meteorological assumptions without the need for more sophisticated meteorological input as would be required by more complex deterministic models. The predictions for the upper percentiles of concentration were obtained with an accuracy that is expected of deterministic models in estimating median concentrations.

An important element in assessing environmental risk is inclusion of the effects of fluctuations in long-term meteorology. Even when pollutant data bases exist they often cover a limited time span. The monitoring period may not include a range of meteorological conditions which are sufficiently representative of dispersive conditions to be expected. Comparison of the meteorology for the two years of monitoring of sulphur dioxide in the Upper Hunter Region with other years suggested that significant increases may occur due to changing meteorology. The point was more clearly demonstrated for maximum acid gas levels in Newcastle. These may change by almost a factor of 3 in one climatological period (30 years) due to meteorological influences alone.

Where environmental problems relate to a loss of amenity, the risk is difficult to quantify. A useful methodology which can be adopted in such situations is to carry out a perception-attitude survey of affected populations and a control group. This turned out to be an effective way of characterising the relationship between the degree of amenity loss and pollutant levels, the relative ranking of the environmental effect in comparison to other environmental problems, and to other general problems in the region.

10

Recommendations

Most of our recommendations relate to the acquisition of more pollutant and meteorological data and, in some instances, to the need for subsequent modelling exercises to illuminate the important deficiencies and uncertainties revealed by our regional assessment. With the information obtained from carrying out these recommendations, the Department of Environment and Planning and the State Pollution Control Commission will be in a stronger position to anticipate levels of resource development which will not compromise air quality expectations within the community. We also make some specific recommendations for further research and analysis of the use of economic incentives as policy instruments which could be integrated into the regulatory pollution control system currently operating in the state of New South Wales. The recommendations and their rationale are as follows:

(a) To ensure the protection of public health, it is important to obtain a **satisfactory measure of the levels of suspended particulates in areas subjected to high dustfall.** Dichotomous sampling is recommended because it can be used to determine the volume of particles in air below threshold sizes which are considered a risk to human health. It is especially important to sample in the area around Ravensworth where sulphur dioxide levels, and possibly nitrogen oxide levels, are relatively significant and there is thus a potential for cumulative effects from the three pollutants.

(b) Our survey results show that **industrial noise** is a problem which directly affects many residents of Maison Dieu, Ravensworth and Broke. There is no data base on noise levels in these areas. It would be useful to monitor these areas for noise levels and compare the results obtained with relevant criteria on the effects of noise.

(c) The State Pollution Control Commission choice of 4 g/m^2/month (annual average) as **a level of dustfall which causes loss of amenity** has been confirmed as a very reasonable interim criterion.

A survey of selected population(s), not necessarily in the Hunter Region, subjected to annual averages between 2 g and 4 g/m^2/month could be used to refine the criterion.

(d) A sufficiently extensive study is needed to estimate **the frequency and heights of meteorological inversion conditions in the Upper Hunter Region,** particularly in the area between Singleton and Muswellbrook.

(e) Concurrent monitoring of sulphur dioxide maxima in the Upper Hunter Region is desirable during part of the extensive study period recommended in (d) for **calibration of a trapping model of pollution.** The model could then be used to estimate the extreme levels to be expected when trapping conditions occur.

(f) Some **nitrogen oxides monitoring** in the vicinity of power stations is also required to refine the basic relationship that we assumed between sulphur dioxide and nitrogen oxides released from power stations. It is also needed to determine the relative concentrations of nitrogen dioxide which is the oxide of nitrogen which presents the greatest health risk. Monitoring should at least be carried out in the populated areas near open cut coal mines around 5 to 10 km from the Liddell power station where cumulative pollutant effects are most likely.

(g) When **Bayswater power station** becomes operational a monitoring exercise for ambient sulphur dioxide concentrations and relevant meteorology is recommended to calibrate a **basic dispersion model** for that source. Ideally the exercises in recommendations (d) to (g) would best cover overlapping periods. The full recommendations are especially important should a new generation of coal-fired power stations in the Upper Hunter Region be contemplated after Bayswater.

(h) A **spatially intensive monitoring exercise should be undertaken in the Newcastle area** to determine the relative proportions of acid gases. Should it be determined that nitrogen oxides make significant contributions to acid gas levels, then separate monitoring of sulphur dioxide and nitrogen oxides should be implemented continuously. This will also help establish the potential for photochemical oxidant problems in the area. Continuous monitoring is needed, rather than just daily averages, because it is likely that short-term (1 to 3 hour averages) air quality standards are more in danger of violation than the longer-term standards.

(i) **Continuous monitoring of wind speed and wind direction** closer to the Newcastle city area is also recommended because of the sensitivity of air quality levels to meteorological change. This would be especially important to implement in advance of further acid gas and particulate emitting industry proposals. With more detailed meteorological information our modelling results could be re-worked to evaluate the potential problems of new industry with more precision.

(j) A study is required to estimate the effect of **long range transport of acid gases** from sources outside Newcastle. The work of Dixon (1984) argues that such effects are significant.

(k) **Future acid gas producing development in the Lake Macquarie, Maitland and Cessnock areas** should also be treated with caution. Monitoring for sulphur dioxide, nitrogen oxides and particulates would help clarify the air quality potential for new developments such as power stations producing these emissions. These exercises would certainly need to be undertaken for the assessment of such development proposals.

(l) In the vicinity of the region's two **aluminium smelters,** continued ambient, vegetation and forage monitoring for the effects of **fluoride emissions** is warranted. Furthermore, any fluoride emission increases in the area impinged by the Alcan smelter at Kurri Kurri, as probably would have occurred with a smelter at Lochinvar, must be considered with extreme caution.

(m) A short period of monitoring to assess the levels of **nitrogen dioxide from motor vehicles** in the Maitland area is recommended. This will allow investigation of any current problem. With a concurrent wind speed and direction monitoring exercise, calibration of a model to predict the likely future impacts in such major through-traffic towns could also be achieved.

There are several **policy options** which should be considered for the management of air pollution in New South Wales. The aim of those suggested for investigation in (n)-(p) below should be either to provide incentives to emitters to reduce their pollution levels as far as possible or to increase the cost-effectiveness of air pollution control or both. The suggestions are particularly relevant to the Hunter Region.

(n) Simulation of **a market for the equitable distribution of pollution quotas** for industry in the Newcastle airshed should be undertaken. While the establishment of an effective pollution market may have problems, the major possibility being lack of sufficient competition, the research costs for investigation of this possibility are low.

(o) **Offsetting of pollutant emissions** allows deregulation of a factory's individual emission sources so that its total emissions of individual pollutants can be considered as a single entity. Some sources may be cheaper to control than others and offsetting allows a factory to control individual sources as it wishes as long as total emissions of any individual pollutant are not increased. Offsetting should be considered for factory complexes up to 2.5 km square.

(p) There is currently some consideration of the use of **emission taxes** as an incentive to reduce air pollution emissions in New South Wales. This should be encouraged and we suggest investigation be made of:

  (1) the gradation of pollution licence fees to small emitters where fees are proportional to emission strengths;

  (2) the scope for continuous monitoring of source emissions from large isolated point sources so that fees can be based on such operations;

  (3) the feasibility of compensation, in proportion to pollution level suffered and some other criteria based upon value of area impinged, for the effects of lead and fluorides from stationary sources and of dustfall. Dustfall and lead compensation schemes warrant immediate attention.

(q) A **central data bank** should be established and administered with sufficient powers to house all relevant environmental data for the region. This would improve the accessibility of data and encourage the assessment process. Data are at present too fragmented among the SPCC, polluters and other monitoring agencies.

(r) There has been too much uncertainty surrounding the prediction of pollution levels (mainly suspended and deposited particulates) emanating from **open cut coal mining activity**. Forecasts are needed by the end of the decade to determine the extent of buffer zones and/or the requisite level of pollution control on mining operations. To accomplish this, special intensive studies are required to relate observed pollution level to emission source type. Extensive data collection over a three to five year period is required to build up a sufficient data base to identify and calibrate a useful model.

(s) Air quality predictions made in Environmental Impact Statements tend to embody average values only. Pollution predictions should delineate the **potential range of impacts** and their probability of occurrence. This would involve more widespread use of **stochastic methodologies.**

to determine the potential range of impacts and the likelihood of occurrence. This could involve more widespread use of stochastic methodologies.

[illegible]

APPENDIX I

Dose-damage threshold information

Introduction

Air pollution dose-damage information is reviewed for identifying the risks of ambient air pollutants to target receptors in the Hunter Region. It has been noted in Chapter 2 that there is in general a safety margin between maximum ambient concentrations and specified damages in the region. Identification of the margin is therefore possible now that techniques such as those detailed in Appendix VII are available for predicting maximum concentrations within a factor of 2 accuracy. The information is of general interest and can be applied to assess the likelihood of air quality impacts in other locations.

In the following specific dose-damage information from the literature is provided for the pollutants of significance in the Hunter Region as noted in Chapter 1. This is in the form of threshold levels at which either no damage or a specified damage has been observed. The thresholds are listed for human health, vegetation and materials and the relevant references to their original source are listed. Some attempt will also be made to incorporate information on synergistic effects. It is worth emphasising that the term threshold is not employed here in its strictest sense. Thus, it is not used to denote a point below which it is assumed no damage occurs but as a general term denoting a point at which the damage to be indicated has been observed.

Fig. 1 in Chapter 1 is a map of the Hunter Region subdivided on the basis of local government areas into the Upper and Lower Hunter Subregions. It shows the location of major development including operational and proposed aluminium smelters and power stations, the major industrial area of Newcastle and the areas of open cut coal mining. Table 1 of Chapter 1 displays the relevant emissions emanating from these developments and vehicular traffic. Emissions known to occur in negligible quantities are not included. From the table, it is seen that the atmospheric pollutants of the Hunter Region for which dose-damage thresholds are required are: sulphur dioxide, particulates including lead, fluorides, nitrogen oxides, ozone and noise. Hydrocarbons and carbon monoxide are not included since these derive mainly from vehicle emissions and seem to be of such levels to be of insignificant consequence compared to nitrogen oxides (*see* Chapter 7). The effects of these are basically restricted to human health and for these effects the interested reader is referred to Ferris (1978).

Damage information

The data for this section are presented as summaries in various tables. Each table relates to a particular pollutant and includes damage thresholds for receptors of interest. Although multiple results are sometimes reported, clearly some subjective judgments need to be made when assessing the literature for relevant results. References are therefore given to allow the reader to find the source or a review of the information so that some reliability can be gauged for the data presented here. The tables also contain the particular USEPA standards for the pollutants and guidelines followed by the NSW State Pollution Control Commission (1982) are shown in the final table. In this way, the reader can assess their relevance to the damage thresholds. All levels are given in micrograms or milligrams per cubic metre and where relevant in parts per million. The conversion units used are for conditions of zero degree Celsius and 1 atmosphere pressure. It should be noted that Ferris (1978) has critically reviewed the health effects of low level exposure to air pollutants from available epidemiological and clinical studies and has subsequently evaluated the adequacy of USEPA primary standards. Our results with respect to health rely heavily on his work.

Sulphur dioxide and particulates

Table 1 contains the relevant summary for these pollutants which should be considered in conjunction with one another since the major health effects result from particulates carrying sulphur dioxide into the lungs.

The information base for long-term health effects of sulphur dioxide and particulates can be regarded as reasonable whereas the results obtained for short-term effects are conflicting (*see* Ferris 1978). There is also a lack of information on the effects of sulphur dioxide on Australian native vegetation. However, most native plants are xerophytic to some degree and the characteristics of xerophytic plants lean them towards

TABLE 1 Sulphur dioxide and suspended particulates

	ppm	SO_2 $\mu g/m^3$	Particulates $\mu g/m^3$	Damage	Ref
HEALTH					
long-term	.014	40	131	No effect	Ferris(1978)
	.021	60	180	Increased respiratory symptoms, decreased pulmonary function	”
	0.25	71	80	No effect	”
short-term	.076-.095	217-271	150-350	Increased frequency of asthma attacks, increased respiratory symptoms of chronic bronchial patients, small reversible reductions in pulmonary function	”
VEGETATION					
long-term (growing season)	.01-.07	29-200	–	yield reduction for vegetables	Irving & Ballou (1980)
	.047	134	–	yield reduction for rye, lucerne, oats	”
	.13	371	–	yield reduction for grapes	”
short-term					
3 hours	.45	1286	–	threshold injury for vegetables	”
24 hours	.26	743	–	threshold injury for grapes	”
	(see text for native grasses and plants and for effects of particulates on vegetation)				
MATERIALS					
long-term	.05-.10	143-286	–	No significant increase in steel erosion	Yocom & Ulpham (1977) Nriagu (1978)
	.10	286	–	No significant increase in erosion rate to paints	Yocom & Ulpham (1977)
	.10	286	–	21% increase in loss of strength for rayon and cotton	”
	.20	571	–	80% increase in loss of strength for nylon	”
	.20	571	–	No increase for polyester or modacrylic	”
	(see text for cumulative effects with particulates)				

Table 1 (Continued)

STANDARDS (USEPA)	ppm	SO_2 $\mu g/m^3$	Particulates $\mu g/m^3$	Averaging time
Primary				
long-term	.03 (annual arithmetic mean)	86	75* (annual geometric mean)	Mean of 24 hour averages
short-term	.14	400	260*	24 hours (not to be exceeded more than once per year)
Secondary	.50	1429		3 hours (not to be exceeded more than once per year)

* These are for particles < 45 µm. New standards are being considered for particles < 10 µm.

TABLE 2 Fluoride

	HF ppm	$\mu g/m^3$	Damage	Ref
VEGETATION				
long-term (growing season)	.00033-.00077	0.3-0.7	5% injury to sensitive plants (grapes, gladiolis, peach, plum, sorghum)	Heck & Brandt (1977) and National Research Council (1971a)
	.00055-.00220	0.5-2.0	5% injury to intermediate plants (most grasses, barley, rye, citrus, oats)	,,
	.00110-	1.0-	5% injury to resistant plants (lucerne, most vegetables)	,,
1 month	.00055-.00110	0.5-1.0	5% injury to sensitive plants	,,
	.00110-.00550	1.0-5.0	5% injury to intermediate plants	
	.00330-	3.0-	5% injury to resistant plants	
1 week	.00083-.00220	0.75-2.0	5% injury to sensitive plants	,,
	.00165-.00880	1.5-8.0	5% injury to intermediate plants	
	.00770-	7.0-	5% injury to resistant plants	
short-term	.00220-.00660	2.0-6.0	5% injury to sensitive plants	,,
8 hours	.00550-.00330	5.0-30.0	5% injury to intermediate plants	
	.02750-	25.0-	5% injury to resistant plants	
12 hours	.00165-.00550	1.5-5.0	5% injury to sensitive plants	,,
	.00440-.0297	4.0-27.0	5% injury to intermediate plants	
	.0242-	22.0-	5% injury to resistant plants	
24 hours	.00110-.00440	1.0-4.0	5% injury to sensitive plants	,,
	.00330-.02200	3.0-20.0	5% injury to intermediate plants	
	.0165-	15.0-	5% injury to resistant plants	
	ppm (forage)	(average equivalent contributing ambient $\mu g/m^3$)		
ANIMALS				
More than 3 months	40-	1.0-	Significant incidence of lameness in dairy cattle, effects on growth, milk production, severe osseous lesions and dental fluorosis.	National Research Council (1971a) and Suttie (1969)
More than 2 months	60-	1.5-		
More than 1 month	80-	2.0-		
Yearly average	40	1.0	Chemical evidence of fluoride ingestion, discernable but non-damaging bone lesions, changes in dentition which do not affect wearing quality	,,

relative resistance to airborne pollutants. These characteristics include high levels of cuticular wax and lower stomatal numbers. Also being mostly perennial and non-deciduous is an advantage since mature leaves are much less sensitive than recently developed leaves. Therefore, we assume that native vegetation is in general less sensitive to airborne pollutants than cultivated or other agricultural crops (Davis and Wilhour 1976).

Damages to vegetation from particulates is not really a problem unless the particulates deposit on leaves in such high amounts that photosynthesis is hindered. In fact, most of the research has concentrated on the effects of cement kiln dusts where, in close proximity to the source (1-2 km) and in the presence of moisture, they form hard crusts that cannot be washed off and can only be removed by force.

However, it is accepted that particulates act in several ways to heighten the effects of sulphur dioxide on metal surfaces (Nriagu 1978): by attracting sulphur dioxide and causing a localised increase in sulphur dioxide concentration; by reducing the humidity level at which corrosion can begin to occur; and by deactivating the protective oxide film on the metal surface. Unfortunately, quantified information is scarce but Nriagu (1978) gives a review of controlled experiments to evaluate the effects of pure compounds on metal corrosion.

Fluoride

Table 2 contains the most relevant results for fluoride. Health and material effects are not considered because the levels necessary for damage are far in excess of those necessary to kill sensitive vegetation. The daily human intake of fluoride inhaled from ambient air is only a few hundredths of a milligram which represents only a small fraction of the normal total fluoride intake. For instance, if a person is exposed to ambient air containing about 1 $\mu g/m^3$ of fluoride, his/her daily intake from this source would be approximately 20 μg whereas it has been estimated that the fluoride intake from other sources such as food and water usually approximates 1200 μg/day (National Research Council 1971a).

Animals, on the other hand, may additionally be exposed to fluoride from ingested fresh forage or hay, feed supplements and the water supply in areas where fluoride pollution is a problem. The damage thresholds for animals in Table 3 have been obtained from controlled experiments (National Research Council 1971a) where a relationship has been assumed between forage concentration and ambient concentration (Suttie 1969).

The damage thresholds specified for vegetation relate to injury defined as any measurable effect on the plant as a result of exposure.

Nitrogen Dioxide

Table 3 provides our summary of damage thresholds for nitrogen dioxide. The other oxides of nitrogen are not considered because nitrogen dioxide alone appears to be the oxide responsible for effects on health (Ferris 1978), vegetation (Taylor *et al* 1975) and materials (Yocom and Ulpham 1977). Unfortunately, there is little quantification of the effects of nitrogen dioxides on materials. However, being an acid gas, nitrogen dioxide would produce similar effects to sulphur dioxide but these effects would generally occur at much higher concentrations. Of course, there are some compounds which react more readily with nitric acid than sulphuric acid.

TABLE 3 Nitrogen dioxide

	NO_2 ppm	$\mu g/m^3$	Damage	Ref
HEALTH				
long-term	.051	.104	No effect on healthy non-smoking adults	Ferris (1978)
	.055	.112	No change in pulmonary function but questionable small increase in respiratory symptoms.	"
	.08	.163	Slight increase in respiratory illness and bronchitis morbidity, slight decrease in pulmonary function	"
short-term				
1/4 hour	1.5	3.062	No change in airway resistance	"
	0.7	1.429	No effect on reaction time or cardiorespiratory performance	"
1 hour	0.11	0.225	Some effects on asthmatics but no overt symptoms or discomfort	"
2 hours	0.3	0.612	No increased response in active subjects	
VEGETATION				
long-term				
1 month	0.14	.286	No damage to any plants	Taylor et al (1975)
1 week	0.25	.510	No damage to any plants	
short-term				
1/2 hour	6-12	12.25-24.50	5% injury to sensitive plants (peas, beans, lucerne, oats, barley)	Heck & Brandt (1977)
	10-25	20.41-51.03	5% injury to intermediate plants (rye, maize, wheat, potato)	
	20-	40,82-	5% injury to resistant plants (gladiolus, onion, cabbage)	"
1 hour	3-10	6.12-20.41	5% injury to sensitive plants	
	9-20	18.37-40.82	5% injury to intermediate plants	
	18-	36.74	5% injury to resistant plants	"
2 hours	2,5-7.5	5.10-15.31	5% injury to sensitive plants	
	7-15	14.29-30.62	5% injury to intermediate plants	
	13-	26.53	5% injury to resistant plants	"
4 hours	2-6	4.08-12.25	5% injury to sensitive plants	
	5-12	10.21-24.50	5% injury to intermediate plants	
	10-	20.41-	5% injury to resistant plants	"

Table 3 (Continued)

	NO_2 ppm	µg/m^3	Damage	Ref
8 hours	1.5-5	3.06-10.21	5% injury to sensitive plants	Hech & Brandt (1977)
	4-9	8.16-18.37	5% injury to intermediate plants	
	8-	16.33-	5% injury to resistant plants	
MATERIALS	.05-5	.102-10.21	Fading in a number of sensitive fabric/dye combinations over 12 week period	Yocom & Ulpham (1977)
STANDARDS (USEPA)			Averaging time	
primary and secondary	.05	.102	Annual arithmetic mean of 24 hour values (not to be exceeded more than once per year)	

Oxidants

As has been pointed out by Ferris (1978), an evaluation of the effects of ozone on health is fraught with many difficulties. These include the reactivity of ozone and its ability to be transported over considerable distances both vertically and horizontally. In addition, the reliability and accuracy of the KI method which has been used extensively to measure total oxidant have been seriously questioned. These limitations, fortunately, should not apply as seriously to controlled experiments on vegetation and materials.

Noise

The major effect of noise pollution is clearly on human health, the severity of which varies according to the intensity and frequency of the sound and the time period of exposure. The range of effects includes hearing loss, increased risk of heart disease, stress, interference with sleep and lack of warning of accidents (Australian Academy of Science 1976; USEPA 1978). Quantification of such effects is difficult, however, because response is considered to vary widely between individuals and because most responses on any individual can only be gauged qualitatively. Consequently, no thresholds are specified here.

Nevertheless, a strong correlation between expressed annoyance and noise intensity has been hypothesised (USEPA 1972) based on a survey of 3,500 people in the United States and another in Sweden. In the latter case, the proportion of people annoyed increased linearly with noise levels above 50 dBA.

Of course, noise may also cause damage to natural or built structures if sufficiently high enough to set up troublesome vibrations.

Lead and human health

Three criticial types of lead toxicity to humans are documented: gastrointestinal cramps (lead colic), central and peripheral nervous system effects (lead encephalitis, wrist drop) and anaemia. Kidney disease, excess frequency of hypertension, and vascular disease have been reported but are not universally accepted as long-term effects (Goldsmith and Friberg 1977). In the following, it is shown that there is sufficient reliable information in the literature to ascertain a reasonable estimate of ambient levels which cause critical and less overt effects.

The critical or threshold average absorbed daily intake of lead for humans from all sources is about 100 μg (Jaworski 1979). Using the lead loss figures of Chamberlain (1983), this gives a steady state load of 5000 μg. Assuming an average blood volume in humans of 6 litres, this yields a steady state blood lead level of 83 μg/100 g. Such a figure agrees well with blood lead levels that cause acute lead toxicity (Goldsmith and Friberg 1977). Now we need to relate this to ambient levels required after subtracting out normal dietary intakes.

The average dietary intake of lead from food is about 160 μg per day of which only 16 μg is absorbed. Additionally, 6 μg per day is absorbed on average from water consumption (Jaworski 1979). Converting these figures to steady state blood concentrations yields 13 μg/100 g and 5 μg/100 g respectively. For the critical level of 83 μg/100 g this leaves 65 μg/100 g at steady state to be derived from ambient sources; that is, 78 μg of lead absorbed from air per day. About fifty percent of the lead inhaled is deposited in the lung (USEPA 1972). Of this 50-80 per cent is absorbed (Goldsmith and Friberg 1977; Chamberlain 1983). Therefore 25-40 per cent of the lead inhaled is absorbed. Given an average volume of air inhaled daily of 20 m^3, this provides a critical average ambient concentration of 9.8–15.6 $\mu g/m^3$.

Goldsmith and Friberg (1977) state that 40–60 μg/100 g blood lead level results in a subclinical metabolic effect manifested by a slight increase in urinary aminolevulinic acid. These levels therefore result from ambient concentrations of 3.3–5.3 $\mu g/m^3$ for 40, and 6.3–10.1 $\mu g/m^3$ for 60 μg/100 g.

The Australian (NHMRC) 90 day standard for lead is 1.5 $\mu g/m^3$ which seems on the above basis to provide a reasonable safety margin to protect health.

TABLE 4 Oxidants expressed as ozone

	O_3 ppm	$\mu g/m^3$	Damage	Ref
HEALTH				
long-term	Los Angeles levels		No evidence that health effects result from chronic exposure	Ferris (1978)
short-term				
1 hour	.06-.11	128-234	No effects on healthy adults	"
	.06	128	No effects on pulmonary function in patients with chronic respiratory disease	"
	0.1	213	Nose, throat and eye irritation	"
	.15	319	Asthmatic attacks more common in some asthmatics	"
VEGETATION				
1 month	.05	106	Reduced root and stem dry weight in tobacco (40%, 30%) and lucerne (20,12%) which are sensitive plant types	Tingey & Reinert (1975)
short-term				
1 hour	.1-.25	213-532	5% injury to sensitive plants (oats, potato, tomato)	Heck & Brandt (1977)
	.2-.35	426-745	5% injury to intermediate plants (wheat, corn, onion)	
	.3-	638-	5% injury to resistant plants (carrots, beets)	
2 hours	.07-.2	149-426	5% injury to sensitive plants	
	.15-.30	319-638	5% injury to intermediate plants	
	.25-	532-	5% injury to resistant plants	"
4 hours	.05-.15	106-319	5% injury to sensitive plants	
	.12-.26	255-553	5% injury to intermediate plants	
	.23-	4890-	5% injury to resistant plants	"
8 hours	.03-.12	64-255	5% injury to sensitive plants	
	.10-.22	213-468	5% injury to intermediate plants	
	.20-	426-	5% injury to resistant plants	"
MATERIALS				
long-term	.1	213	No effect on painted surfaces	Yocom & Ulpham (1977)
	.05-.5	106-1064	Fading in a number of sensitive fabric/dye combinations over 12 week period	
STANDARDS (USEPA)			Averaging time	
short-term primary and secondary	.12	170	1 hour (not to be exceeded more than once per year)	

TABLE 5 State Pollution Control Commission (NSW) objectives

Pollutant	Standard	Agency
*Acid gases (24 hour)	60 $\mu g/m^3$ (Annual mean)	WHO
*Suspended matter (24 hour)	40 $\mu g/m^3$ (Annual mean)	WHO
Total suspended particulate	90 $\mu g/m^3$ (Annual geometric mean)	NHMRC
	260 $\mu g/m^3$ (24 hour maximum)	USEPA
Lead	1.5 $\mu g/m^3$ (90 day average)	NHMRC/USEPA
Carbon monoxide	35 ppm (1 hour maximum)	WHO/USEPA
Non-methane hydrocarbons	24 pphm (3 hour maximum)	USEPA
Nitrogen dioxide	17 pphm (1 hour maximum)	NHMRC
	5 pphm (Annual arithmetic mean)	USEPA
Ozone	12 pphm (1 hour maximum)	NHMRC/USEPA
Sulphur dioxide	14 pphm (24 hour maximum)	USEPA
	2 pphm (Annual arithmetic mean)	NHMRC

* Acid gases and suspended matter considered in conjunction with one another.

Pollutant combinations

Human health

Since nearly all the data on the effects of multiple pollutants on human health are derived from field (ie usually urban or industrial) exposures, it is often difficult to delineate the effect of one pollutant in the 'soup' from another. Because of this, there is very little hard data on the effects of pollutant combinations, except for sulphur dioxide and particulates, on human health. This delineation problem is especially evident in the case of sulphur dioxide and nitrogen dioxide. These two acid gases usually occur at similar concentrations in an industrial environment, but the effects of the nitrogen dioxide are usually either ignored or incorporated into the sulphur dioxide effects.

Materials

Again the information of pollutant combinations is minimal. The effects of nitrogen dioxide on the corrosion of metals etc., goes virtually unmentioned, and there has been no effort made to delineate between the effects of sulphur dioxide and nitrogen dioxide. Corrosion by sulphur dioxide has been demonstrated to be enhanced by particulates (see earlier section) and retarded by oxidants (*see* Yocom and Ulpham 1977). Apart from these examples there is very little information on the effects of pollutant combinations on materials.

Vegetation

The literature on the effects on vegetation of interaction between pollutants, or between a pollutant and another factor is also very scarce. The work that has been done is often inconclusive and because of the methods employed, unable to be compared with other similar work. Despite these short-comings, the evidence is mounting that certain pollutant combinations actually cause effects equal to, or greater than the sum of the effects of the pollutants individually, that is the pollutants act additively or synergistically.

Varshney and Garg (1979) and Reinert *et al* (1975) incorporate short reviews of the effects of various combinations of pollutants. It is generally their conclusion that sulphur dioxide/nitrogen dioxide, sulphur dioxide/hydrogen fluoride and sulphur dioxide/ozone act additively or synergistically on various plant types, on various mechanisms, and at a range of concentrations. These effects may be to lower threshold concentrations, cause more damage or dysfunction, or alter growth characteristics. Although the trends are obvious, quantification of the effects are still far from adequate, and therefore the economic significance of pollutant combinations is still unknown.

APPENDIX II

Institutional framework for environmental control and planning

In the following sections the institutional arrangements in New South Wales for the control of environmental quality and the management and planning of the environment in general are discussed. The salient features of the major legislative mechanisms used to accomplish these aims, the Clean Air Act and the Environmental Planning and Assessment Act, the administration of these Acts as well as the complementary roles of the Department of Environment and Planning and its associated control agency, the State Pollution Control Commission, are outlined.

In Chapter 8, the control philosophy of the State Pollution Control Commission which is based upon best practicable means, is presented and compared with alternatives.

Clean air legislation in NSW

The Clean Air Act 1961 commenced operation in May 1962 and regulations under the act were proclaimed in 1964 prescribing a wide range of emission standards. The Act was amended in 1972 to allow the control of open-burning and also regulations relating to the control of motor vehicle emissions. By 1974 there were regulations to control emissions of smoke, hydrocarbons and carbon monoxide from motor vehicles and also regulations controlling odours. In 1975 regulations were introduced to limit the lead content of petrol sold in Sydney, Newcastle and Wollongong as well as controls on evaporative emissions from motor vehicles.

Gilpin (1980) summarises the Clean Air Act as follows:

> The Clean Air Act provides for the control of air pollution from any premises and prescribes that certain works may not be carried out without approval. The occupier of premises may be required to carry

out appropriate works. Emission standards may be prescribed and enforced; where such standards have not been prescribed, the best practicable means are to be used to prevent or minimize air pollution. Licensing provisions apply to premises scheduled under the act. Conditions designed to prevent or reduce air pollution may be attached to the licence. The act prohibits the sale or use of motor vehicles that emit excessive air impurities, and provides for the fitting of anti-pollution devices. The minister may prohibit the use of fuel or any class of fuel, fuel-burning plant or industrial plant, in nominated areas. He may order the cessation of any activity which is, or is likely to be, injurious to public health or to cause discomfort or inconvenience to persons. Aggrieved persons have a right of appeal to the District Court. Penalties under the act are up to $10,000 for a single offence, and $5,000 for each day the offence continues.

In addition to the Clean Air Act, the SPCC uses as guidelines some of the ambient air pollution criteria set by the United States Environmental Protection Agency (USEPA), the National Health and Medical Research Council of Australia (NHMRC) and the World Health Organisation (WHO). These criteria are given in Table 4 in Appendix I. They are not used strictly as environmental standards never to be violated but rather as a guide in the achievement of a desired level of environmental quality when negotiations through best practicable means between polluter and control agency takes place.

The government agencies associated with air pollution control

Initially the Health Commission of NSW was responsible for pollution control. Then, in 1971, the State Pollution Control Commission (SPCC) was given responsibility for the prevention and control of pollution in NSW under the State Pollution Control Act 1970. The functions of the SPCC as outlined in sections 11 and 12 of the Act, are to ensure

> that all practical measures are taken . . . to prevent, control, abate or mitigate the pollution of the environment, to control or regulate the disposal of waste, to protect the environment from defacement, defilement or deterioration, to co-ordinate the activities of all public authorities in relation thereto, to initiate and undertake research into measures adopted to achieve those aims, and to provide information and guidance on pollution control methods (Bates 1983).

Bates (1983) describes the relationship between the SPCC and other bodies in the following way:

> To assist the Commission in carrying out its functions, there is a Technical Advisory Committee . . . which is made up of representatives from all other public services which in some way have an interest in the formulation of pollution control policy. Represented, for example, are the Departments of Health, Transport and Public Works, the National Parks, Waste Disposal, Planning and Conservation Authorities, and the Sewage and Maritime Services Boards, as well as other technical experts. The commission also has its own advisory committees on clean waters, air pollution and noise, and these also contain experts from appropriate public, technical and environmental bodies. Apart from administering the Clean Air Act 1963, the Clean Waters Act 1970 and the Noise Control Act 1975, one of the commission's most important continuing functions is to undertake environmental inquiries . . . and field studies and investigations into matters of particular environmental concern.

Gilpin (1980) describes the operation of the SPCC as follows:

> To implement the Clean Air Act, the Commission employs engineers, chemists, and technicians, who engage in day-to-day control activities, monitor air pollution levels in the atmosphere, and conduct research into the scientific aspects of the problem. Source testing plays an important part in the implementation of emission standards; the practical aspect of this work has been well developed over the years.

However, under the Environmental Planning and Assessment Act 1979, the responsibility for environmental planning and environmental impact assessment is now with the Department of Environment and Planning (DEP) created by this Act. Bates (1983) summarises the involvement of this body and other government agencies with the SPCC as follows:

> Responsibility for environmental planning and environmental impact assessment, however, falls within the competence of the new Department of Environment and Planning created under the Environmental Planning and Assessment Act 1979. One of the department's concerns under this act is 'the emission of pollution and means for its prevention or control or mitigation'. Naturally, the task of the Pollution Control Commission will be greatly assisted by the sensible planning of new development, and so provision for adequate consultation between the two is of extreme importance if pollution control policy is to be really effective in the years ahead. The commission is accordingly represented on the Advisory Co-ordinating Committee, which advises the minister on the content and priorities to be set by

> environmental planning instruments, and the co-ordination of effort between all public authorities involved in environmental planning and protection . . . The commission also has a seat on the Local Government Liaison Committee for similar reasons . . . The treatment and disposal of waste, including sewage and trade wastes, does not fall within the State Pollution Control Commission's terms of reference. Responsibility for this rests either with the local councils under the Local Government Act 1919 or, in the Sydney area, with the Metropolitan Waste Disposal Authority (under the Waste Disposal Act 1970) and the Metropolitan Water, Sewerage and Drainage Board (under the Metropolitan Water, Sewerage and Drainage Act 1938). Local councils also have significant powers to control pollution under the Clean Air and Clean Waters Acts, the Public Health Act 1902, the Noise Control Act and the Noxious Trades Act 1902 . . . prevention of pollution in or on navigable waters is also the responsibility of the Maritime Services Board. Under the authority of the Maritime Services Act 1935 the board has made regulations controlling water and smoke pollution, and is also responsible for the administration of the Prevention of Oil Pollution in Navigable Waters Act 1960. The board also has powers to control noise under the Noise Control Act 1975. Because of this division of function amongst other bodies, overall policy co-ordination is assisted by including on the commission's Technical Advisory Committee representatives of the various boards and other authorities.

Environmental planning in NSW

The definition of the environment adopted in the 1979 Act includes all aspects of the surroundings of man, whether affecting him as an individual or in his social groupings.

The concept of environmental planning adopted by the Department of Environment and Planning is described by Bosward and Staveley (1982) in a discussion paper as follows:

> The nature and scope of environmental planning are broader and more comprehensive than the 'land use' or 'town and country planning' approach which was adopted in the former planning system. Environmental planning is directed to questions of land resource allocation and use, the essential difference of this approach to that taken under the Local Government Act is its more complete concern for and comprehension of community and environmental issues relative to planning decisions. The term connotes an integration of land

use planning and techniques for environmental protection with respect to assessing the capability of the environment to support planned change or planned non-change.

A major requirement of such an approach is the implementation of an environmental study before major planning decisions are made. An essential part of such a study is the drawing up of an environmental impact assessment (EIA) or environmental impact statement (EIS).

Administration

Bosward and Staveley (1982) give a detailed account of the administration of the 1979 Act. We shall only briefly describe the adminstrative arrangements here.

The Minister for Planning and Environment is the minister responsible under the Act for its implementation and administration. The Director of Environment and Planning has advisory functions with the Minister and, in some cases, executive power. The Department of Environment and Planning assists both the Minister and the Director and confines itself to matters of State or Regional significance. The preparation and administration of local environmental plans is the responsibility of local government councils.

The Land and Environment Court has been established by the Land and Environment Court Act 1979 and is administered by the State Attorney-General. The Court has jurisdiction in appeals and legal proceedings in the related fields of environmental planning, pollution control, local government, land valuation and compensation. Commissioners of Inquiry are created by the Environmental Planning and Assessment Act 1979 and are responsible for the undertaking of a Commission of Inquiry when directed by the Minister for Planning and Environment. These Commissioners are appointed for seven years and hold a Statutory office.

Commissions of Inquiry are public inquiries which may be called by the minister, but are not subject to Ministerial direction. These commissions lead to public reports and recommendations to the Minister. There are also committees formed to allow interaction between the heads of government agencies affected by planning, the representatives of local government, and the representatives of conservation groups, developers, professionals, and academics.

Three types of environmental planning instruments are created by the Environmental Planning and Assessment Act:

- State Environmental Planning Policies, involving broad issues such as issues in planning land;
- Regional Environmental Plans, in which regions are not established by the Act but are declared as regions by the Minister to allow flexibility of application;
- Local Environmental Plans, which must be approved by the Director as being consistent with State and Regional Plans prior to the Minister's approval.

Bosward and Staveley (1982) note that 'local plans will continue to be the primary vehicle of development control and planning regulation'.

The Act also describes three types of development—'normal', designated, and advertised. The first two require environmental impact statements relating to development defined in the Act as possibly having environmental effects, while the last is envisaged as contentious rather than affecting the environment.

Public participation is allowed through submissions to the consent authorities relating to proposed plans, submissions to a Commission of Inquiry should the Minister call one, and finally by appeals to the Land and Environment Court if there are disagreements with the decisions of the court authorities on a Commission of Inquiry. Most of the disagreement centres around the environmental impact statement (EIS) prepared by a developer.

Environmental Impact Assessment (EIA)

An EIS or EIA report sets out the conclusions of an environmental study carried out by a developer. For example, for a power station there would be references to air quality impact, noise effects, water resource use, to name but a few. Bosward and Staveley (1982) sum up the NSW experience as follows:

> From the review of a number of environmental impact statements and an overall experience in environmental impact assessment, it is apparent that both developers and consent or determining authorities have experienced difficulties relating to consideration of development in the environment due mainly to a lack of experience in addressing environmental issues. To date, we have been progressing through a transitional stage from a time when little attention was given to environmental impact to a time when the ultimate in consideration is being sought. Most of this transition has occurred in less than a decade—with the greatest development taking place, as far as Australia is concerned, in the last five years. Many of the proposals that have

been presented to date were conceived and developed before techniques for environmental impact assessment were evolved.

The SPCC may be called upon by the Department of Environment and Planning to comment on sections of an EIS and even to collect information regarding possible effects. For instance, in the Hunter Region under study in this monograph we have detailed in Chapters 3-6 the monitoring network set up by the SPCC in co-operation with such organisations as the Newcastle City Council and the State Electricity Commission of NSW. We have made a number of suggestions in those chapters as to how such a network might be improved.

Fowler (1982) makes the following points about the relationships between an EIA and pollution controls:

> The need to question the role of EIA arises from the possible existence of adequate or adaptable existing controls. However, since pollution controls are levelled at only one specific aspect of a proposal, rather than its comprehensive or overall impact, they are much more limited in scope than either EIA or land-use planning systems, and do not therefore present a viable alternative; rather, they constitute an adjunct to whatever form of comprehensive project appraisal method is preferred.

There are also limits to the power of the control agency as Fowler points out:

> The narrow ambit of pollution controls in Australia has been underlined in two recent decisions concerning the Victorian Environment Protection Authority. The High Court had held that the Authority is empowered to have regard only to environmental considerations in exercising its licensing functions, and must disregard economic or social factors. It is doubtful, however, that the Authority can consider even the full range of considerations arising from a proposal which may relate to environmental quality in general, rather than the specific subject of pollution. The further judical limitation has been imposed on the Authority that, in exercising its licensing functions, it may only impose such conditions as fairly and reasonably relate to the activity or use being licensed. Hence, the Authority could not deal with the problem of odours emanating from an abattoir by way of conditions attached to a licence for air emissions from two chimneys on the premises. In licensing air pollution, the Authority must confine its attention to matters related to the project air emissions.

This judgment has implications for other control agencies as Fowler indicates:

These restraints arose in the context of the particular legislation governing the functions of the Victorian Environment Protection Authority, but it is reasonable to assume that similar restrictions apply to most pollution control systems in Australia. In relation to licensing functions involving the assessment of particular proposals, it would seem likely that the pollution control authorities are confined to a consideration of the relatively narrow compass of the specific forms of pollution involved in each instance, according to the general tenor of the legislation which they administer.

Public participation in EIA

The Environmental Planning and Assessment Act provides for public participation at a number of stages in the plan-making and development control process. Any person may participate in the following processes by making submissions (Bosward and Staveley 1982):

Plan-making—exhibitions of local environmental studies, draft local environmental plans (any person may also request a hearing of their submission before the local council), regional environmental studies, draft regional environmental plans, draft state environmental planning policy;

Development control—exhibitions of advertised development, designated development (where submission is an objection, the objector may appeal to the Court or be heard at a Commission of Inquiry);

Part V of the Act (relates to government and semi-governmental agencies not requiring official development consent)—exhibition of an EIS (any person may attend a Commission of Inquiry).

Thus there are facilities for participation throughout the entire planning process. In addition the Minister may intervene in the decision-making process for any development application or any matter related to the administration of the Act and by doing so is obliged to call a Commission of Inquiry to investigate.

APPENDIX III

Environmental survey questionnaire

The Australian National University
Centre for Resource and Environmental Studies

Environmental effects survey

This is a survey to see what parts of your environment affect your life style and how important each part is to you, as an individual, and also to your family. Some of the questions are factual and some are concerned with the way you feel about things. Please try to complete all the questions. There are no 'right' or 'wrong' answers. Thank you for your cooperation.

Background information

1. Sex ____________

2. (a) What is your occupation? ____________

   (b) If you have a spouse, what is his/her occupation? ____________

3. Age 16–25 ____________

   26–35 ____________

   36–45 ____________

   46–55 ____________

   56–65 ____________

   66–75 ____________

   76 + ____________

4. In what year did you come here? 19______

5. (If applicable)

   (a) Before you came here where did you live? ____________

   (b) For how long? ____________

(c) Why did you leave? ____________________

6. (a) If you had the choice, where would you like to live most? ____________________

(b) Why? ____________________

7. What are three most enjoyable things about living here? (eg being in a wine-making region)

1. ____________________
2. ____________________
3. ____________________

8. What are three things you like least about living here? (eg poor shopping facilities)

1. ____________________
2. ____________________
3. ____________________

9. What are three things you would like to change most about living here? (eg bumpy roads)

1. ____________________
2. ____________________
3. ____________________

10. (a) Compared to the last place you spent some time (at least a year) how much do you like living here? (Please circle)

Very much less Less Neutral More Very much more

(b) Why? ____________________

____

____

11. Below are a list of things which some people find upsets their enjoyment of living both in the house and outside. Please indicate how you feel about these things by ticking the description you think best represents your feelings

	It annoys me a lot	It annoys me a little	I have no feelings about this
Industrial smoke			
Litter on streets			
Large trucks			
Industrial noise			
Dust			

Cigarette smoke

Litter in recreational areas

Industrial odours

River pollution

Lack of sewerage

Too close to a main road

12. Now please go through the list again but this time tick the category you think best represents how often you notice these things.

	I notice it almost every day or every time I see it	I notice it some days or sometimes when I see it	I notice it only on days when it is worse than usual	I rarely notice it now but I used to	I don't notice it at all
Industrial smoke					
Litter on streets					
Large trucks					
Industrial noise					
Dust					
Cigarette smoke					
Litter in recreational areas					
Industrial odours					
River pollution					
Lack of sewerage					
Too close to a main road					

13. If any of these things listed in question 11 above *directly* affects your life could you indicate

(a) which (b) how they affect you (c) what you do about it

1. (a) ______________________
   (b) ______________________
   (c) ______________________

2. (a) ______________________
   (b) ______________________
   (c) ______________________

3. (a) ______________________
   (b) ______________________

4. (a) ______________________
   (b) ______________________

(c) ______ (c) ______

If you need more space, please write on the back of the sheet.

14. Do you feel that something could be done about these things? ______

______

15. Whose responsibility do you think it is to do something about these things? ______

______

Health background. Only to be filled in if not answered by another household member

16. During the last six months please indicate approximately how many times you or your family went to a doctor.

Myself
0-4 times ______
5-9 ______
10-14 ______
15-19 ______
20 + ______

Child 3
0-4 times ______
5-9 ______
10-14 ______
15-19 ______
20 + ______

Child 1
0-4 times ______
5-9 ______
10-14 ______
15-19 ______
20 + ______

My Spouse
0-4 times ______
5-9 ______
10-14 ______
15-19 ______
20 + ______

Child 2
0-4 times ______
5-9 ______
10-14 ______
15-19 ______
20 + ______

Other family members
0-4 times ______
5-9 ______
10-14 ______
15-19 ______
20 + ______

17. Please indicate for yourself and your family what the most common reason(s) for visiting the doctor were:

Ear infection ______

Colds/Flu ______

Stomach Problems ______

Bronchial Problems ______

Allergies ______

Coughs ______

Headaches ______

Asthma ______

Other (please specify) ______

18. Are any of these pre-existing problems which have been around for a long time? If so, please indicate when the problem arose and who has it.

______ has been around for ______ months/years

______ is the one suffering from it

19. Which if any of your family smokes? ______________________________

20. What appliances do you have in your homes that are there because of environmental problems? (eg air cleaner)

____

____

____

____

____

APPENDIX IV

Dustfall levels

Dust deposition data in or near the regions surveyed is summarised in Table 6. The accompanying figures 1 to 5 indicate the locations of the gauges and the populations more precisely.

TABLE 6 Representative dustfall levels for locations surveyed

		Dustfall Levels*			Average Levels* over all gauges		
Location	Period	No. Gauges	Mean g/m^2/month	Std. dev. g/m^2/month	Time Period	Level (Range) g/m^2/month	Source
Broke	Aug 78-	2	0.94	0.66	7 months	0.68	A
	May 79		0.42	0.28		(0.4-0.9)	
	Jan 81-	2	1.2	0.7	12 months	0.9	B
	Dec 81		0.6	0.3		(0.6-1.2)	
	Mar 82-	4	0.8	0.5	10 months	1.3	B
	Jan 83		1.1	0.6		(0.8-2.5)	
			2.5	1.5			
			0.9	0.5			
Maison Dieu	Jun 81-	11	3.21	2.55	7 months	6.2	C
	Dec 81		8.64	9.42		(1.0-16.5)	
			10.73	10.9			
			9.38	8.7			
			0.99	0.51			
			2.76	3.00			
			16.45	16.5			
			6.25	8.6			
			1.85	0.49			
			6.79	7.42			
			1.41	0.59			
Murrurundi	No data available						
Ravensworth	Apr 80-	3	4.52	3.53	12 months	3.6	D
	Jul 82		4.88	10.61		(2.0-6.4)	
			3.84	3.57			
			3.66	2.61			
			2.16	1.89			
			2.71	2.13			
	May 77-	1	2.74	2.08	12 months	2.6	
	Jul 82					(1.7-3.0)	

South Muswellbrook	May 77- Jul 82	1	1.68	0.88	12 months	1.7 (1.5-2.0)	D
	Jan 81- Dec 81	1	2.08	1.58	12 months	2.1	E
Warkworth	Dec 80- May 81	8	0.45	0.24	6 months	0.8 (0.4-1.1)	F
			0.43	0.26			
			1.06	0.71			
			0.64	0.28			
			0.89	1.37			
			0.47	0.29			
			0.63	0.25			
			0.44	0.21			
	Nov 76- Mar 80	1	1.89	2.46	12 months	1.7 (1.2-2.1)	F

* Insoluble solids for gauges in representative areas of the region concerned.

\# Overall gauges. 12 month averages are taken from the commencement of the data set.

Sources A Preliminary EIS for Saxonvale Mine
B Saxonvale Annual Reports (Environmental Aspects)
C Buchanan Boreholes Colliery
D Electricity Commission
E Muswellbrook Council
F United Colliery Project EIS

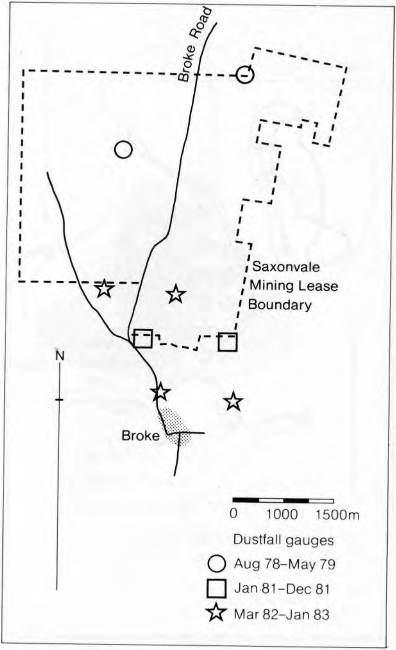


FIGURE 1 Location of dustfall gauges and populations surveyed in the Broke area

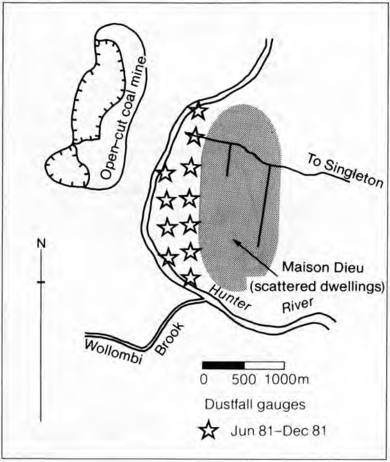


FIGURE 2 Location of dustfall gauges and populations surveyed in the Maison Dieu area

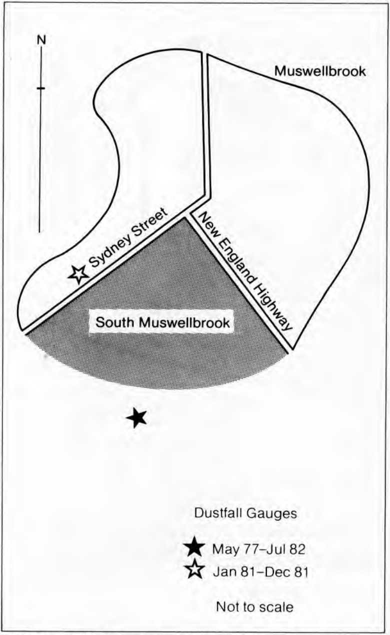


FIGURE 3 Location of dustfall gauges and populations surveyed in the South Muswellbrook area

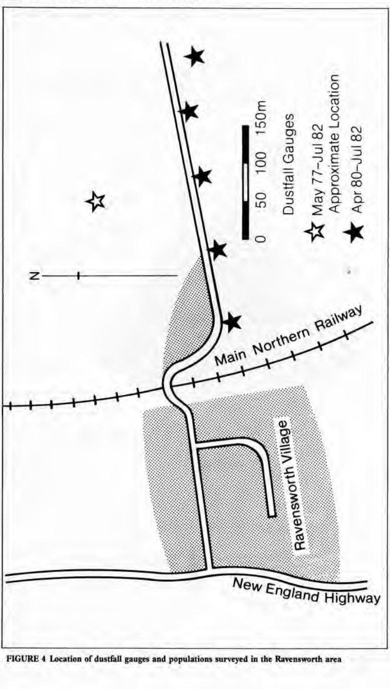


FIGURE 4 Location of dustfall gauges and populations surveyed in the Ravensworth area

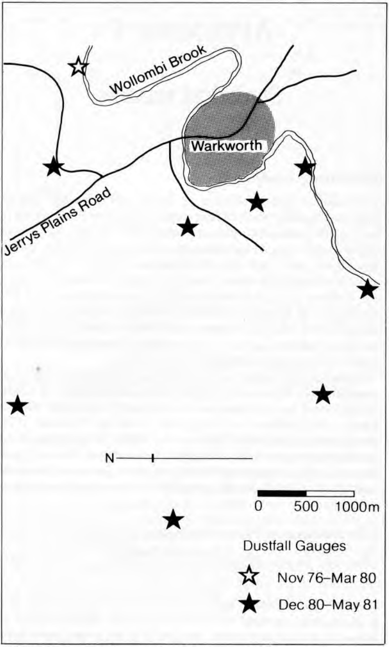


FIGURE 5 Location of dustfall gauges and populations surveyed in the Warkworth area

APPENDIX V

Statistical models

The Larsen model

The statistical model developed by Larsen (1971) assumes that air pollution concentrations have two-parameter lognormal frequency distributions. Two-parameter lognormal cumulative frequency distributions plot as straight lines on lognormal probability paper, where the natural logarithm of the air pollution concentrations are plotted against Z, the number of standard deviations from the median. An example of such a plot is shown in Fig. 6 where the 1981 24 hour concentrations of SO_2 recorded at the Watt Street station in Newcastle are plotted in such a way. It is clear from Fig. 6 that a straight line is a good fit to the upper percentile ordinates so that a two-parameter lognormal distribution appears to be a good representation of such data.

Numerous investigators have disputed the validity of the lognormal assumption (eg Mage and Ott 1978). This is acknowledged by Larsen (1973) himself but it is also true that the model works quite well (eg Larsen 1971, McGuire and Noll 1971, Shoji and Tsukatani 1973, Bencala and Seinfeld 1976, Surman *et al* 1982). Certainly the results such as those shown in Fig. 6 support the conclusion that the Larsen model is a mathematical model which is useful in forecasting maximum levels of air pollutants and the number of times a standard is equalled or exceeded.

The two-parameter frequency distribution is of the form

$$f(\chi) = (\sqrt{2\pi}\ \chi \ln \beta)^{-1} \exp \left[- \frac{(\ln \chi - \ln \alpha)^2}{2 \ln^2 \beta} \right] \qquad \text{(A1)}$$

were $f(\chi)$ is the probability density function for the random variate χ, β is the geometric standard deviation, and α is the geometric mean. It follows from equation (A1) that estimates of α and β completely determine the distribution.

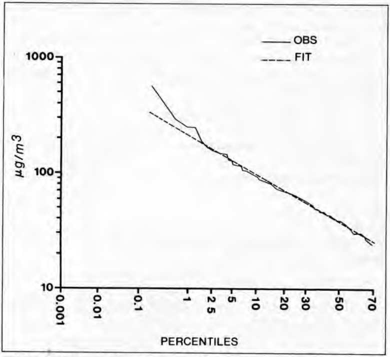


FIGURE 6 Cumulative frequency distribution for daily acid gas levels (at Watt St for 1981).

The estimation of α and β adopted by Larsen (1971) is simple and straightforward and therefore useful to air pollution control managers. The cumulative frequency distribution of a two-parameter lognormal distribution plots as a straight line using lognormal probability plots and the slope of this straight line is $\ln \beta$. Therefore Larsen (1971) suggested using two points on the cumulative frequency distribution of the air pollution observations to determine this slope. For example, for most cases Larsen (1971) suggested using the 0.1- and 30-percentile ordinates to determine this slope. However any two ordinates could in principle be used if the lognormal assumption was valid. In Fig. 6 it is clear any two ordinates from the 1- to the 50-percentile points could be used.

So β is given by

$$\beta = \exp\left\{ \frac{\ln \chi_1 - \ln \chi_2}{Z_1 - Z_2} \right\} \tag{A2}$$

where χ_1 and χ_2 are the air pollution concentrations corresponding to the Z values, Z_1 and Z_2, respectively. For the 0.1- and 30-percentiles, $Z_1 = 3.09$ and $Z_2 = 0.52$. In Fig. 6, since 24 hour concentrations are used for a data set of one year, the 1-percentile point is clearly preferable to the 0.1-percentile point and the Z-value for this is 2.33. For the data used in Fig. 6 then,

$$\beta = \exp\left\{ \frac{\ln (168) - \ln (59)}{2.33 - 0.52} \right\} = 1.78$$

The values obtained by fitting a straight line to the upper 50 per cent of the data is 1.89.

The value of α was estimated by Larsen (1971) using the relation

$$\alpha = \frac{\chi}{\beta^{z}} \tag{A3}$$

where χ is the concentration corresponding to Z. For the data in Fig. 6, using the 30-percentile point,

$$\alpha = 59/(1.78)^{0.52} = 44\ \mu\mathrm{gm}^{-3}$$

For a two-parameter lognormal distribution the geometric mean is the median, and the median in Fig. 6 is 40 μgm^{-3}.

The maximum concentration χ_m is given by

$$\chi_m = \alpha\, \beta^{Z_m} \tag{A4}$$

where Z_m is the Z-value corresponding to the time period of interest. For example, for 24 hour values, Z = 2.94 (see Larsen 1971). So, for Fig. 6,

$$\chi_m = (44) \times (1.78)^{2.94} = 240\ \mu\mathrm{gm}^{-3}$$

or

$$\chi_m = (40) \times (1.89)^{2.94} = 260\ \mu\mathrm{gm}^{-3}$$

The observed maximum is 188 μgm^{-3}. In Chapter 5 it was mentioned that, as the sulphur dioxide observations used in Fig. 6, were collected 5 days/week then a value of $Z = 2.83$ would be more appropriate in comparing the estimates using the Larsen model and the observed maximum. Using $Z = 2.83$ the estimates are 225 μgm^{-3} and 242 μgm^{-3}, respectively, little different from those for $Z = 2.94$.

The WHO standard for 24 hour values of sulphur dioxide is an annual mean of 60 μgm^{-3} and a level of 200 μgm^{-3} not to be exceeded more than 2 per cent of the time, and this 2 per cent is not to be on consecutive days.

Using Larsen's model, the Z-value, Z_s, corresponding to a given standard, χ_s, is simply

$$Z_s = \frac{\ln \chi_s/\alpha}{\ln \beta} \tag{A5}$$

For $\alpha = 44$, $\beta = 1.78$, $\chi_s = 200$, then $Z_s = 2.63$. For $\alpha = 40$, $\beta = 1.89$, $\chi_s = 200$, then $Z_s = 2.53$. So the probability of the standard being equalled or exceeded is between 0.0086 ($Z = 2.63$) and 0.0118 ($Z = 2.53$). For 24 hour concentrations for a year, this is 3 to 4 times per year for 365 days or 2 to 3 times per year for 260 days (∿ 5 days/week). The standard is observed to be exceeded only once, with a probability ∿ 0.005. There were four high values deleted in December of 1981 after consultation with the SPCC. However it is clear that the WHO standard still is not exceeded for 1981 even with all the data used since 2 per cent of the time requires the value of 200 μgm^{-3} to be exceeded more than 7 times a year. Obviously the Larsen model is of little use in determining whether a standard is exceeded on consecutive days. Continuous monitoring would be necessary to determine this.

Larsen (1971) has also developed an empirical model which relates frequency distributions at different averaging times. The empirical mathematical model proposed by Larsen has the following assumptions:

(a) concentrations are lognormally distributed for all averaging times;
(b) the median concentration is proportional to the averaging time raised to an exponent;
(c) the arithmetic mean concentration is the same for all averaging times;
(d) for the longest averaging time calculated (usually one year), the arithmetic mean, geometric mean, maximum and minimum concentrations are all equal; and
(e) the maximum concentration is approximately inversely proportional to the averaging time raised to an exponent, for averaging times of one month or less.

Larsen has used those assumptions to forecast maximum concentration at one averaging time using the parameters from another averaging time. In particular he has shown that

$$\begin{aligned} \beta_2 &= \beta_1^{\nu} \\ \nu &= \frac{\ln (t_{tot}/t_2)}{\ln (t_{tot}/t_1)} \end{aligned} \tag{A6}$$

where t_{tot} is the largest averaging time (usually one year) at which assumption (d) holds, and

$$\alpha_2 = \alpha_1\beta_1\ 0.5\ (1 - \nu)\ \ln\beta_1$$

where β_1 and β_2 are the geometric standard deviations corresponding to averaging times t_1 and t_2, respectively, and α_1 and α_2 are the corresponding geometric means. The estimated maximum concentration, (eg Larsen 1971) χ_m, is given by equation (A4).

Therefore, using α_1 and β_1, it is possible, to estimate α_2 and β_2 and thus, from equation (A6), the corresponding maximum. In fact, from assumption (e), Larsen suggests a form

$$\chi_{m2} = \chi_{m1} \left(\frac{t_1}{t_2}\right)^p \tag{A7}$$

where χ_{m1} and χ_{m2} are the maximum concentrations corresponding to averaging times t_1 and t_2, respectively, and p is estimated from β_1, t_1, and the maximum t_1, χ_{m1}.

An important assumption in Larsen's model is the use of order statistics. The plotting position frequency is given in percent by

$$f = 100 \left(\frac{r - 0.4}{N}\right) \% \tag{A8}$$

where, r = rank order of observation and N is the number of observations. The use of such an approach implies that the observations are independent, clearly an assumption not satisfied for most air pollution data sets, as indicated by Patel (1973), Neustadter and Sidik (1974), Darby and Gregory (1976), and Horowitz and Barakat (1979). However, in response, Larsen (1973) stresses the empirical nature of the model and that its usefulness be measured by its performance. This is the approach adopted here.

The exponential model

The Larsen model outlined in (A6) is useful in analysing data in an airshed with a large number of sources eg Newcastle. However, it is not useful in analysing data from a single point source such as the Liddell power station.

The SO_2 data collected at Glennies Creek monitoring site approximately 16 km SE of the power station are shown in Fig. 7 for a year of data, 1/11/80–30/10/81, for which 86 per cent of the ½ hourly data were available. Fig. 7 shows the cumulative frequency distribution plotted on

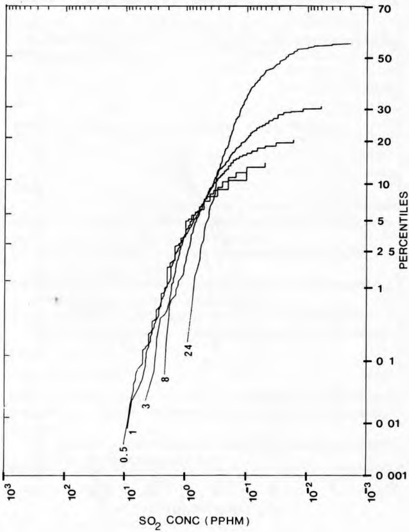


FIGURE 7 Cumulative frequency distributions of SO_2 data at Glennies Creek on a lognormal scale for ½ hour, 1 hour, 3 hour, 8 hour and 24 hour time averages.

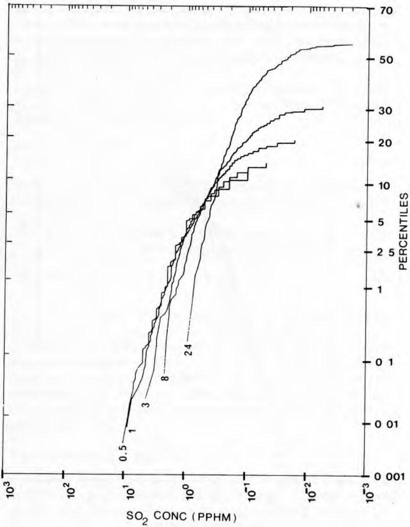


FIGURE 8 Same as in Figure 7 but using an exponential scale.

a lognormal scale. In Fig. 8 the same data is plotted on an exponential scale. Clearly the exponential distribution is a better representation of the data and statistical tests confirm this.

The probability density function, $f(\chi)$, for a one-parameter exponential distribution is

$$f(\chi) = \frac{1}{b} \exp\left(-\frac{\chi}{b}\right) \qquad \text{(A9)}$$

and the cumulative frequency distribution, $F(\chi)$ is given by

$$F(\chi) = \exp\left(-\frac{\chi}{b}\right) \qquad \text{(A10)}$$

where $F(\chi) = \text{prob}\ (\chi \geq x)$.

Simpson *et al* (1984) have suggested a one-parameter exponential model for non-zero data to relate the maxima at different averaging times from a single point source. The model assumes

(a) the air pollution data due to a single isolated point source have an exponential distribution;

(b) the maximum concentration is approximately inversely proportional to the averaging time raised to an exponent; and

(c) the observed arithmetic mean is the same at all averaging times.

From these assumptions it is possible to derive a relationship between χ_{m1} and χ_{m2} of the form

$$\chi_{m2} = \mu^{1-\nu} (\chi_{m1})^{\nu} \qquad \text{(A11)}$$

where ν is defined in equation (A6). This relationship is easily derived from (A7) given that the maximum at the longest averaging time is just the mean μ.

The maximum, χ_{m1} of an exponential distribution for averaging time t_1 defined by the scale parameter, b, is

$$\chi_{m1} = b \ln\left(\frac{1}{P_m}\right) \qquad \text{(A12)}$$

with P_m = probability of maximum, χ_{m1},

and

$$P_m = \left(\frac{0.6}{N_1}\right) \qquad \text{(A13)}$$

with N_l being the number of sample points at averaging time t_l.

found (e.g. Simpson *et al* 1984) to be applicable to exponential distributions as well.

Simpson *et al* (1984) have shown that the model using the 8 hour data set to forecast the maxima at the 3 hour, 1 hour and ½ hour time averages yields good results. An attempt to use the 24 hour average data sets to reproduce the maxima for an 8 hour, 3 hour, 1 hour and ½ hour data sets yielded poor results.

Other distributional models and methods

In a series of papers, Taylor *et al* (in press) and Jakeman *et al* (in press) investigate methodologies for identifying the most appropriate distributional form for air quality data and for estimating the parameters in the form identified. The lognormal, gamma, Weibull and exponential distributions are used as examples.

APPENDIX VI

Mathematical models for atmospheric dispersion

The Gaussian plume model and ATDL model have been well documented by many investigators (e.g. Turner 1970) and only the model forms adopted in this monograph are detailed here. We consider first the two plume models used in Chapter 4 to predict concentrations from an elevated point source. In the following section, the Gaussian line source model used in Chapter 7 is presented. Finally, a brief description of the ATDL model used in Chapters 5 and 7 is given.

Gaussian plume model for point sources

The model predicts that the ground level concentration, χ_{glc}, due to a point source release at height Z_s is given by

$$\chi_{glc}\,(x, y, o, H) = \frac{Q\,10^9}{\pi\,\sigma_y\,\sigma_z\,u}\,\exp\,(-\frac{y^2}{2\sigma_y{}^2})\,\exp\,(-\frac{H^2}{2\sigma_z{}^2}) \qquad \text{(A14)}$$

where x is the horizontal wind direction and y the horizontal crosswind direction, Q is the source strength (kgs^{-1}, u is the horizontal wind speed (ms^{-1}), σ_y and σ_z are the horizontal and vertical dispersion parameters (m), and H is the effective height of emission (m). χ_{glc} is in μgm^{-3}.

The experimental validity of this model has long been a question of conjecture but most investigators support the conclusion of Pasquill (1974) that it is a reasonable representation of time-averaged observations of one hour or more. More recently Lamb (1979) has shown that numerical simulations of dispersion of non-buoyant plumes from elevated sources agree reasonably well with equation (A14).

Given equation (A14), two other submodels are needed. Values of σ_y and σ_z are required, and a submodel for plume rise, ΔH, where

$$H = Z_s + \Delta H \qquad \text{(A15)}$$

The experimental work of Carras and Williams (1983) and Chambers *et al* (1982) has established that the empirical values of σ_y and σ_z determined by Carras and Williams (1981) in their investigation of the Mt Isa smelter plumes are reasonable representations of the dispersion parameters for the Liddell power station for convective conditions. Carras and Williams (1983) have also shown that their values compare favourably with those of Lamb, shown in Table 7. Lamb's values were derived from numberical simulations of nonbuoyant elevated emissions. The Carras and Williams (1981) values are

$$\sigma_y = \sigma_z = 3.5t^{0.67} \tag{A16}$$

where t = time of travel. As seen in Table 7 Lamb suggests that σ_z is proportion to t, instead of $t^{0.67}$ as suggested by Carras and Williams. Carras and Williams (1983) argue the reason for the difference with Lamb's results are because Lamb deals with nonbuoyant releases while the Mt Isa experimental work of Carras and Williams (1981) is based on buoyant releases. Carras (1983) has also suggested restricting σ_z to $\sigma_z \leq$ ½ h, where h is the height of the inversion layer, by analogy with Lamb who has restricted $\sigma_z \leq$ ⅓ h for non-buoyant releases and $Z_s > 0.1$ h. (Carras and Williams (1983) have shown that, for Liddell, $Z_s \geq 0.1$ h).

The submodel used for the computation of plume rise ΔH, by Carras and Williams (1981) is a correction to the Briggs' (1975) formula:

$$\Delta H = 1.3\ F^{1/3} \times {}^{2/3}\ u^{-1} \tag{A17}$$

where F is a buoyancy flux parameter. The factor, 1.3, has replaced the factor, 1.6, used by Briggs. Carras and Williams (1981) found that the buoyant Mt Isa plume on average stopped rising in convective conditions about 100s after leaving the stack so the final plume rise, ΔH_f, is

$$\Delta H_f = 1.3\ F^{1/3}\ (100\ u)^{2/3}\ u^{-1}$$

or

$$\Delta H_f = 28.0\ F^{1/3}\ u^{-1/3} \tag{A18}$$

Chambers *et al* (1982) suggest using for Liddell power station the plume rise formula of Montgomery *et al* (1973) of

$$\Delta H = 190\ F^{1/3}\ u^{-1} \exp\{-0.64 \frac{\partial \Theta}{\partial z}\} \tag{A19}$$

where $\partial\Theta/\partial z$ is the vertical potential temperature gradient (degrees Kelvin/100 m). Chambers *et al* also derived an empirical relationship for F of

$$F = 1.45\ P \tag{A20}$$

where P = the power (MW) generated by the units connected to each stack at Liddell power station. For example, during the intensive study period at Liddell power station in which both the Carras and Williams group and the Chambers *et al* group were involved, Carras and Williams (1983) measured a mean value of F of 700 m^4s^{-3}, quite comparable to the value of Chambers *et al* of approximately 769 m^4s^{-3}.

However the two formulae given by (A18) and (A19) for plume rise are quite different. For $F = 700\ m^4s^{-1}$ and $\partial\Theta/\partial z = O$, equation (A19) becomes

$$\Delta H = 1687/u \tag{A21}$$

In fact the form of (A21) is very similar to the result obtained using the Briggs' formula for final plume rise.

$$\Delta H_f = 1.6\ F^{1/3}\ (3.5\ x^\star)^{2/3}\ u^{-1} \tag{A22}$$

where

$$\begin{aligned} x^\star &= 34\ F^{2/5}\ \text{(since } F > 55\text{)} \\ &= 467 \quad \text{(for } F = 700\text{)} \end{aligned}$$

Therefore

$$\Delta H = 1.6\ F^{1/3}\ (1635)^{2/3}\ u^{-1} \tag{A23}$$

Using 1.3 instead of 1.6 as suggested by Carras and Williams (1981), (A23) becomes

$$\Delta H_f = 1602/u \tag{A24}$$

quite comparable with (A21). So the Montgomery *et al* (1973) result is similar to Briggs (1975). However, as pointed out by Carras and Williams (1981), for low wind speeds (A21) and (A24) suggest plume rises over a kilometre. On the other hand Chambers *et al* (1982) have shown the model results using (A21) are quite good. A comparison of results using the two different plume rise calculations is shown in Fig. 9 for both summer and winter situations.

Following the results of Bridgman and Chambers (1981), the summer values of Q and P chosen where 1.58 kgs^{-1} and 530 MW, respectively, and the winter values were 1.75 kgs^{-1} and 850 MW, respectively. From Carras and Williams (1983), the summer values of $x^\star$ and h chosen were 2 ms^{-1} and 1500 m respectively. Since Venkatram (1983) has suggested that the ratio $x^\star/h$ is constant, the winter values of $x^\star$ and h chosen were 1.5 ms^{-1} and 1000 m respectively.

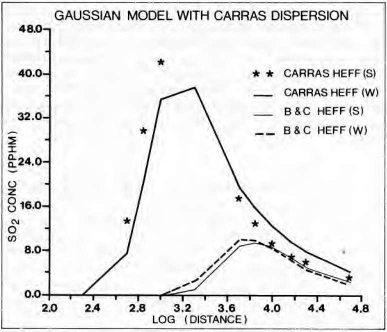


FIGURE 9 Summer and winter dispersion for two different plume rise assumptions.

The results plotted in Fig. 9 are for the maximum sulphur dioxide value occurring at each distance. The maximum sulphur dioxide value was computed by finding the critical wind speed at which the maximum occurred for each distance.

Bridgman and Chambers (1981) found that use of the Montgomery *et al* formula for plume rise yields good agreement with observation. In Fig. 9 it is seen that the use of this formula predicts a maximum sulphur dioxide level of about 10 pphm occurring at about 6 km from the power station. The observed maximum was found to be of the order of 20 pphm between 5-7 km from the source. On the other hand the model predictions using the plume rise formula suggested by (A18) predict the maximum to be about 40 pphm about 1 km from the power station. On the basis of these results, the Montgomery *et al* formula given by (A19) has been used here. Since observations of $(\partial\Theta/\partial_z)$ are not available for our work it has been assumed that $\partial\Theta/\partial_z = 0$. As we only consider model applications during the day between 1000 and 1500 hours then, from Bridgman and Chambers (1981) observations of $\partial\Theta/\partial z$ this assumption is reasonable for these time periods during winter 1980 and summer 1980/81.

The maximum SO_2 levels recorded around Liddell power station probably occur due to 'trapping' conditions. The mechanism envisaged starts with the plume for the power station emitted into a stable atmosphere at night and staying aloft as a radiation inversion sets in beneath a subsidence inversion. At sunrise the radiation inversion begins to break up and the plume is brought to the ground. If the subsidence inversion persists throughout the morning then the emissions from the power station will be 'trapped' by this inversion layer and will not be able to rise any further and subsequently more pollution will occur at ground level than would have if the subsidence inversion were not there.

In such circumstances the Gaussian plume formula becomes (e.g. Turner 1970),

$$\chi\,(x,o,o,H) = \frac{Q\,10^9}{(2\pi)^{1/2} u\, h\, \sigma_y} \tag{A25}$$

Montgomery *et al* (1973) have used this model for TVA power stations and derived a model of the form

$$\chi\,(x,o,o,H) = \frac{10^9\,Q}{(2\pi)\,{}^{1/2}\,\sigma_{yt} zs\, U} \tag{A26}$$

Where

zs = height of the trapping inversion,

$\sigma_{yt} = 1.32 \times 0.55 + 0.47\,[Ht/1.1 - (2.15)\,(6.71) \times 0.21]$

The different expression for σ_{yt} is an acknowledgement that there is more crosswind spreading in trapping conditions.

To convert the prediction to 1 hour average readings Montgomery *et al* (1973) suggests dividing equation (A26) by 2. Chambers *et al* (1982) suggest multiplying by 0.47, about the same factor. We have used the Montgomery *et al* factor.

Gaussian line source model

The form of Gaussian line source model used in this monograph in Chapter 7 is known as the GM model (Chock 1978). It calculates the concentrations at height z above the ground and distance x from the source using the equation

TABLE 7 Values of σ_y, σ_z suggested by Lamb* (1979)

$$\sigma_y/h = \begin{matrix} 1/3\,X & X \leq 1 \\ 1/3\,X^{2/3}, & < X \leq 3 \end{matrix} \quad \text{for } z_s^{**} > 0.1\,h$$

$$\sigma_z/h = \begin{matrix} 1/2\,X, X \leq 2/3 \\ 1/3, X > 2/3 \end{matrix} \quad \text{for } z_s^{**} > 0.1\,h$$

where $X = \frac{x}{h} \; \frac{w^*}{u}$,

with x = horizontal distance directly downwind,
h = inversion height,
w^* = convective velocity parameter,
u = horizontal wind speed,
z_s = height of emissions.

* These results are only valid for $h/-L > 10$, $z_s/-L > 1$, $1.2\,w^* \leq u \leq 6\,w^*$ (where L is the Monin Obukhov length)

** Carras and Williams (1983) have shown that this condition is satisfied at Liddell power station for February 1981.

$$C(x,z) = \frac{Q}{\sqrt{(2\pi)}u\sigma_z} \{\exp[-\frac{1}{2}(\frac{z + h_o}{\sigma_z})^2] + \exp[-\frac{1}{2}(\frac{z - h_o}{\sigma_z})^2]\} \quad \text{(A27)}$$

where Q is the emission rate per unit length, u is the effective crossroad wind speed and h_o is the plume height. The effect of vertical dispersion on the distribution of concentration is represented by the dispersion parameter σ_z. The functional form given for σ_z is

$$\sigma_z = (a + bx)^c \quad \text{(A28)}$$

where a, b and c are dependent on atmospheric stability and x again is the distance from the source.

The values of the parameters a, b and c as given in equation (A28) are those evaluated by Chock (1978) from experimental observation under the three fundamental atmospheric stability categories, (stable, neutral and unstable). This model is applied only where the wind speed is greater than 2 ms^{-1} so the values for neutral atmospheric stability ($a = 1.14$, $b = 0.10$ and $c = 0.97$) were chosen.

The plume height h_o requires no correction for plume rise when the wind speed is greater than 1 ms^{-1}. Thus h_o is the source height. For a stream of traffic consisting of both light duty and heavy duty vehicles a value of h_o = 1m was adopted although the sensitivity of this assumption is demonstrated in Chapter 7.

ATDL model

For a grid pattern with uniform source strengths in each square, the ground level concentration, χ_o, in a grid square, is given for the ATDL model by

$$\chi_o = (2/\pi)\ ½\ (\Delta x^{1-b}\ [u\ a(1-b)]^{-1}\ \{Q_o + \sum_{i=1}^{N} (2i + 1)^{1-b}\ ] \qquad (A29)$$

where N is the number of upstream grid squares contributing to the grid square under consideration (designated by the subscript "o"), a and b are parameters dependent on atmospheric stability, Δx is the size of the grid square, u is the average horizontal wind speed (assumed to be in the x–direction), and Q_i ($i = 0,1,2 \ldots N$) are the area source strengths for each grid square.

The above equation may be simplified to

$$\chi_o = \frac{CQ_o}{u} \qquad (A30)$$

where C is a constant which depends on atmospheric stability. Equation (A30) follows from equation (A29) only for smooth area source distributions in which the terms involving Q_i ($i \neq 0$) in equation (A29) are significantly less than the Q_o term. This assumption is valid for the towns investigated where the central business districts contain a confined high density–low speed traffic flow.

TABLE 8 Hourly values of the parameter $C/\bar{C}$ where $\bar{C}$ is the average daily value of $C = \chi_0\ u/Q_0$

Hour of day	$C/\bar{C}$
6–7	0.78
7–8	0.71
8–9	0.71
9–10	0.61
10–11	0.53
11–12	0.57
12–13	0.49
13–14	0.47
14–15	0.47
15–16	0.48
16–17	0.50
17–18	0.57

Source: Hanna (1978)

The diurnal variation of the stability factor, as $C/\bar{C}$ where $\bar{C}$ is the average daily value, in the simple ATDL dispersion model was determined by Hanna (1978) and has been employed in our calculations. The data are given in Table 8 and were derived from observed variations of CO concentrations, traffic frequencies and wind speeds. These data were employed by Hanna to predict CO concentrations in a Los Angeles airshed with an accuracy as good as or better than more complex models. Using CO concentrations for Canberra, Australia, a similar diurnal variation in the stability factor to that of Hanna was observed.

APPENDIX VII

The CRES model for urban air pollution levels

Two basic approaches have been adopted in air pollution modelling attempts to simulate the dispersion of air pollutants (eg for point sources see Appendix VI). A number of reviews exists for deterministic urban models (eg Simpson and Hanna 1981). The statistical modelling approach consists of estimating the frequency distributions for the air pollutants and estimating the expected maximum concentration and the number of times a standard is exceeded. Examples of such an approach are detailed in Appendix V.

More recently an attempt has been made to combine both approaches in constructing air quality models at the Centre for Resource and Environmental Studies (CRES) (Simpson *et al* 1983 present the first combined or hybrid model for urban area sources). This work has consisted of using the Atmospheric Turbulence and Diffusion Laboratory (ATDL) model of Gifford and Hanna (1973) to estimate the median urban air pollution levels and then to compute the cumulative frequency distribution from these results using the method of Larsen. The CRES model has been applied to a one-year record of 8 hour carbon monoxide data for Canberra and a one year record of daily total suspended particulate data for Brisbane (Simpson *et al* 1983) and found to be satisfactory for both. However the model was less satisfactory for short-time averaged data (eg 1 hour). The approach has also been applied to ten years of daily averages of acid gas levels from Newcastle in Chapter 5. It follows from this work that it is possible to estimate how the fluctuations in the long term meteorology over this period affect the observed maximum acid gas concentrations. The CRES model for urban area sources is briefly described in this Appendix. Implementation of the approach to line and point sources and to further area source data has also very recently been validated (Taylor *et al* 1985a, 1985b, Jakeman and Taylor 1985).

The ATDL model

As shown in Appendix VI the ATDL model developed by Gifford and Hanna (1973) uses a simple relationship between wind speed, u, and air pollution concentration, χ. In its simplest form, as developed by Hanna (1971), this relationship is

$$\chi = \frac{C\,Q}{u} \tag{A31}$$

where Q is source strength and C is a constant depending on atmospheric stability. Simpson and Hanna (1981) have shown that such a model compares quite well with more complex models in predicting mean concentrations for inert gases.

The deterministic part of the method consists of assuming a relationship between air pollution concentration, χ, and wind speed, u, given by

$$\chi = K/u \tag{A32}$$

where $K = CQ$ from (A31). Therefore the constant K depends on source strength and atmospheric stability. Theoretically C may change by up to an order of magnitude with change in atmospheric stability, but Hanna (1971) has shown that the empirical evidence suggests only a weak dependence of C on atmospheric stability.

The CRES model

The CRES model as used here makes two assumptions: (1) the air pollution data and wind speed are lognormally distributed, and (2) there is an inverse relationship between the opposing percentile values of wind speed and air pollution in the statistical distributions of the data.

Condition (1) has been observed to be valid for many air pollution data sets eg Larsen (1969, 1971) and Surman *et al* (1982). Condition (2) is similar to the assumptions underlying the ATDL model.

It can be shown (eg Bencala and Seinfeld 1976) that if u and χ are related by equation (A32) and, if the wind speed frequency distribution is two-parameter lognormal, then the air pollution concentration frequency distribution is two-parameter lognormal. Theoretically, only two points are needed to determine the parameters of a two-parameter lognormal cumulative frequency distribution (eg *see* Larsen 1971), but, given the errors in the data, some form of fitting procedure is preferable.

Assume that the wind speed u, and concentration χ, are related by

$$\chi = g(u) \qquad \text{(A33)}$$

where g(u) is a monotonically decreasing function of u.

Let $F(\chi)$ be the probability that the concentration is greater than or equal to χ

i.e. $F(\chi) = \text{Prob}\ (x \geq \chi)$

Let $G(u) = \text{Prob}\ (U \geq u)$.

Then it follows that

$$\begin{aligned} F(\chi) &= \text{Prob}\ (g(U) \geq g(u)) \\ &= \text{Prob}\ (U \leq u) \end{aligned}$$

since g(u) is a monotonically decreasing function of u. Consequently

$$F(\chi) = 1 - G(u) \qquad \text{(A34)}$$

Therefore the p-percentile ordinate F(p/100) on a cumulative frequency distribution for χ should correspond to the (100-p)-percentile ordinate, G(1-p/100), on the distribution for u. If we assume equation (A32) where K is a constant,

ie $\chi = \dfrac{K}{u}$

the product of the opposite percentile (abscissae) values of concentration and wind speed for these percentile ordinates should yield the same values for K. This is shown in Table 9 for Watt St acid gas data.

Given conditions (A31) and (A32) we can *predict* maximum levels. For a two-parameter lognormal distribution the maximum air pollutant level, χ_m, is given by

$$\chi_m = \alpha_\chi \beta_\chi^{Z_m} \qquad \text{(A35)}$$

(eg *see* Larsen 1971) where α_χ is the median concentration of air pollution data, β_χ the geometric mean, and Z_m the number of standard deviations from the mean corresponding to the percentile point for the maximum value. Larsen (1971) has used (0.6/N) as the probability corresponding to this value, where N is the number of points used. Here N varies ranges from 237 to 260 points (e.g. N = 260, Z = 2.83).

Our model implies that the β value of the wind data, β_u, is the same as β_χ, and that

$$\alpha_\chi = \frac{K}{\alpha_u} \qquad \text{(A36)}$$

following (A32). For example, in Table 7, it is clear that the 50-percentile point lies in the valid range for applying equation (A32). In practice, therefore, we have adopted the simple procedure of estimating K from (A36), ie

$$K = \alpha_\chi \, \alpha_u \qquad \text{(A37)}$$

using β_u in (A35), yielding for χ_m, the expression,

$$\chi_m = \frac{K}{\alpha_u} \, \beta_u Z_m \qquad \text{(A38)}$$

The results of using (A38) are shown in Table 9 for Mounter St and Watt St. The observed maxima are also shown for comparison.

It is clear that the model does quite well, the notable differences occurring when the lognormality assumption is invalid and also perhaps, given the discussion in the last section, because the simple inverse relationship in (A31) is not always appropriate. Nevertheless the accuracy is of the order of a factor of 2 in general which is as good as can be expected. Simpson and Jakeman (1984) show in detail how the model may be used to estimate the effect of long-term meteorological change in the wind speed distributions on maximum levels.

TABLE 9 Estimates of K ($\mu gm^{-2}s^{-1}$) for wind speed, u, in the range, $2 \leq u \leq 4$ ms^{-1}

	Year								
Percentile* Ordinates	1972			1977			1981		
P	u	χ	K	u	χ	K	u	χ	K
35				2.01	25	50			
40	2.11	49	103	2.21	24	53	2.01	47	94
45	2.27	44	100	2.42	22	53	2.11	44	93
50	2.52	39	98	2.73	21	57	2.27	40	91
55	2.73	35	96	2.88	20	58	2.57	36	93
60	2.94	33	97	3.24	19	62	2.78	32	89
65	3.24	29	94	3.45	18	62	2.94	30	88
70	3.60	25	90	3.81	17	65	3.45	25	86
75	3.91	21	82				3.76	21	79
80							3.97	17	67

* These percentile ordinates correspond to greater than, or equal to, probabilities for SO_2 observations; eg in 1972, 40 per cent of all SO_2 data were greater than or equal to 49 μgm^{-3}. However the percentile points correspond to less than or equal to probabilities for wind speed (see equation A35) eg in 1972, 40 per cent of the wind speed data were less than or equal to 2.11 ms^{-1}. Thus $u = G^{-1}(1\text{-}p/100)$ wind speed in ms^{-1}, $\chi = F\text{-}1\ (p/100)$ concentration SO_2 in μgm^{-3}.

TABLE 10 **Comparison of estimated maxima (χ_m) and observed maxima (χ_o) for acid gas data (in μgm^{-3}) at Watt St and Mounter St monitors for 1972-81**

Year	Watt St		Mounter St	
	χ_m	χ_o	χ_m	χ_o
1972*	223	149	217	112
1973	71	79	64	54
1974	78	89	101	165
1975	137	86	159	187
1976	97	96	112	140
1977*	149	49	135	96
1978	93	68	80	85
1979	83	82	98	115
1980	139	143	135	119
1981	223	250	158	169

* discrepancies between model predictions and observations explained in text.

REFERENCES

Anon. 1982. 14,000 vehicles use Dunolly Bridge in a day. *Singleton Argus.* September 22: 6.

Australia. Committee on Motor Vehicle Emissions. 1982. *Report on the development of a long-term national motor vehicle emissions strategy prepared for the Australian Transport Advisory Council.* Canberra: Australian Government Publishing Service.

Australian Academy of Science. 1976. *Report of a committee on the problem of noise.* Canberra: The Academy. (Australian Academy of Science. Report; no. 20).

Australian Environment Council. 1983a. *The costs of pollution abatement: a preliminary survey of nine Australian industries.* Canberra: Australian Government Publishing Service. (AEC report; no. 12).

Australian Environment Council. 1983b. *The costs of pollution abatement: the Australian integrated steel industry.* Canberra: Australian Government Publishing Service. (AEC report; no. 13).

Australian Environment Council. 1983c. *The costs of pollution abatement: the Australian petrochemical industry.* Canberra: Australian Government Publishing Service. (AEC report; no. 14).

Avery, R.A. 1982. A preliminary study on the occurrence of acid rain around Newcastle, NSW. University of Newcastle. Thesis. BSc Honours.

Avery, R.A. 1984. A preliminary study of rainwater acidity around Newcastle, NSW. *Clean Air.* 18: 94–103.

Barker, M.L. 1984. Environmental quality control: regulation or incentives? *Environmental and Planning Law Journal.* 1(3): 222–232.

Basarin, V. and Cook, P.E. 1982. A survey of public attitudes to industrial odours. *Clean Air.* 16: 23–30.

Bates, G.M. 1983. *Environmental law in Australia.* Sydney: Butterworths.

Baumol, W.J. and Oates, W.E. 1977. *Economics, environmental policy and the quality of life.* Englewood Cliffs, New Jersey: Prentice-Hall.

Bencala, K.E. and Seinfeld, J.H. 1976. On frequency distributions of air pollutant concentrations. *Atmospheric Environment.* 10(11): 941–950.

Bergsteiner, McInnes and Rigby. 1976. *Singleton planning study: prepared for the Council of the Shire of Singleton.*

Blackman, S.A. and Baumol, W.J. 1980. Modified fiscal incentives in environmental policy. *Land Economics.* 56(4): 418–431.

Bosward, J.H. and Staveley, P. 1982. *The integration of procedures for assessing the environmental effects of particular projects with procedures for national/state/province and regional planning: integration of environmental planning and impact assessment in New South Wales.* Sydney: NSW. Dept of Environment and Planning. (Discussion paper).

Bridgman, H.A. 1980. The mesoclimatology of the Hunter Valley (with emphasis on wind and precipitation). In. *Hunter environment: proceedings of a symposium in honour of A.D. Tweedie, 1980 August 22nd, Department of Geography, University of Newcastle.* Newcastle: University of Newcastle: 2.1–2.14.

Bridgman, H.A. 1983. Private communication to Newcastle City Council, Health Division.

Bridgman, H.A. 1986. Private communication.

Bridgman, H.A. and Chambers, A.J. 1981. *Air quality in the middle Hunter Valley: the intensive study periods: a report to the N.S.W. State Pollution Control Commission.* Newcastle: Department of Mechanical Engineering, University of Newcastle. (T.N.-FM60-July 1981).

Bridgman, H.A., Chambers, J.C. and Kalma, J.D. 1983. *The contribution of industrial fossil fuel use to groundlevel sulphur dioxide concentrations in the lower Hunter region.* Newcastle: Board of Environmental Studies, University of Newcastle, Australia. (Board of Environmental Studies. Research paper; no. 8).

Briggs, G.A. 1975. Plume rise predictions. In. Haugen, D.A., ed. *Lectures on air pollution and environmental impact analysis.* Boston, Mass: American Meteorological Society: 59–111.

Brookshire, D.S. and others. 1979. *Methods development for assessing air pollution control benefits.* Washington DC: United States. Environmental Protection Agency. v.1–5.

Butt, J.A., Daly, A.M., Daly, N.J. and Jakeman, A.J. 1983. *Hunter Valley environmental survey data.* Canberra: Centre for Resource and Environmental Studies, Australian National University. (CRES paper; 11).

Butt, J.A., Daly, N.J. and Jakeman, A.J. 1982. *Dust in the Hunter Valley: assessing the effects of open cut coal mines.* Canberra: Centre for Resource and Environmental Studies, Australian National University. (CRES paper; 6). See also Proceedings of Half-Day Symposium on Dust Suppression, Newcastle Chemical Engineering Group, 1982 Aug. 10: 3–11.

Carras, J.N. 1983. Private communication.

Carras, J.N. and Williams, D.J. 1981. Observations of near-field plume dispersion under extremely convective conditions. In. Webb, K.A. and Smith, A.J., eds. *Proceedings of the Seventh International Clean Air Conference.* Ann Arbor, Michigan: Ann Arbor Science: 403–427.

Carras, J.N. and Williams, D.J. 1983. Observations of vertical plume dispersion in the convective boundary layer. In. *Proceedings of the 6th Symposium on Turbulence and Diffusion, 1983 March.* Boston: American Meteorological Society.

Carras, J.N. and Williams, D.J. 1984. Measurements of plume dispersion coefficient during convective conditions at various sites widespread around Australia. In. *Proceedings, Eighth International Clean Air Conference, May 6–11, Melbourne:* 507–516.

Chamberlain, A.C. 1983. Effect of airborne lead on blood lead. *Atmospheric Environment.* 17(4): 677–692.

Chambers, A.J. and Bridgman, H.A. 1984. Sector modelling sulphur dioxide dispersion in the middle Hunter Valley, NSW. In. *Proceedings 8th International Clean Air Conference, May 6–11, Melbourne:* 907–922.

Chambers, A.J., Bridgman, H.A. and Long, G. 1982. Dispersion of a buoyant plume from tall stacks in the middle Hunter Valley. *Clean Air.* 16: 68–73.

Chock, D.P. 1978. A simple line-source model for dispersion near roadways. *Amospheric Environment.* 12(4): 823–829.

Cohen, A.A. and others. 1972. Asthma and air pollution from a coal-fueled power plant. *American Journal of Public Health.* 62: 1181–1188.

Coleman, E.J. and Sinclair, M.A. 1979. *Liddell area: climatic dataset Dec. 1979.* Power Development Division, Electricity Commission of NSW. (Dataset; no.PD49).

Cordner, J.P. 1981. General industry view on the costs and benefits of environment protection. In. *Costs and benefits of environment protection.* Canberra: Australian Government Publishing Service: 26–37.

Court, J. and Wilcox, J. 1984. Economic incentives for the control of air pollution in Australia. In. *Proceedings Eighth International Clean Air Conference, May 6–11, Melbourne.*

Covello, V.T. 1982. The perception of technological risks: a literature review. Washington D.C.: United States National Science Foundation. Unpublished manuscript.

Daly, N.J. 1978. Frequency distributions of oxidant forming potentials in Australia as an aid to policy. In. *Proceedings International Clean Air Conference, Brisbane.* Ann Arbor, Michigan: Ann Arbor Science.

Daly, N.J. 1979. The use of frequency distributions of potential ozone in evaluating policy options. *Environmental Science and Technology.* 13: 13–73.

Daly, N.J. 1981. *A guide to the control of photochemical pollution.* Canberra: Australian Government Publishing Service. (Bureau of Transport Economics. Occasional paper; 41).

Daly, N.J. and Jakeman, A.J. 1984a. Environmental assessment in regional development with reference to the atmospheric environment of the Hunter Valley. Part 1: Risk assessment. In. Kissling, C.C. and others, eds. *Regional impacts of resource development.* Croom Helm Australia: 183–202.

Daly, N.J. and Jakeman, A.J. 1984b. Environmental assessment in regional development with reference to the atmospheric environment of the Hunter Valley. Part 2. Modelling. In. Kissling, C.C. and others, eds. *Regional impacts of resource development.* Sydney: Croom Helm Australia: 202–207.

Daly, N.J. and Steele, L.P. 1975. Air quality in Canberra: report to the Department of Capital Territory. Unpublished.

Daly, N.J. and Steele, L.P. 1976. A predictive model for carbon monoxide in Canberra. In. *Symposium on Air Pollution Diffusion Modeling, 1976 August 18–20, Canberra.* Canberra: Dept of Environment, Housing and Community Development: 264.

Darby, W.P. and Gregory, C.J. 1976. Comment on 'On evaluating compliance with air pollution levels not to be exceeded more than once a year'. *Journal of the Air Pollution Control Association.* 26(3): 233–234.

Davis, D.D. and Wilhour, R.G. 1976. *Susceptibility of woody plants to sulphur dioxide and photochemical oxidants.* Corvallis Environmental Research Laboratory, U.S. Environmental Protection Agency.

Dean, M. 1985. Personal communication.

Dennis, R.L. 1978. *The smeared concentration approximation method: a simplified air pollution dispersion methodology for regional analysis.* Laxenburg, Austria: International Institute of Applied Systems Analysis. (IIASA research report 78–9).

Dixon, B.F. 1984. Elevated inversions and the dispersion of pollutants in the Hunter Region. Canberra, Australia: Australian National University. Thesis. Master of Resource and Environmental Studies.

Electricity Commission of New South Wales. 1979. *Bayswater power station: environmental impact statement, June 1979.* Sydney: The Commission.

Electricity Commission of New South Wales. 1981. *Annual report for the year ended 30th June 1981.* Sydney: The Commission.

Electricity Commission of New South Wales. 1982. *Annual report for the year ended 30th June 1982.* Sydney: The Commission.

Feldstein, M. 1976. A new modeling technique for air pollution control. *Environmental Management.* 1(2): 147–157.

Ferrari, L.M. and Ross, I.B. 1983. Monitoring and modelling air quality around mining, smelting and processing operations. In. *Papers Australian Mining Industry Council Environmental Workshop, 1983 September 26–30, Hunter Valley.* Sydney: Australian Mining Industry Council: 80–99.

Ferris, B.G. 1978. Health effects of exposure to low levels of regulated air pollutants: a critical review. *Journal of the Air Pollution Control Association.* 28: 482–497.

Fischhoff, B. and others. 1981. *Acceptable risk.* New York: Cambridge University Press, USA.

Fowler, R.J. 1982. *Environmental impact assessment, planning and pollution control measures in Australia.* Canberra: Australian Government Printing Service.

Freeman, A.M. 1979. *The benefits of air and water pollution control: a review and synthesis of recent estimates.* Washington, DC: Council on Environmental Quality.

Fullick, K. 1984. Personal communication from Newcastle City Council, Health Division.

Gifford, F.A. and Hanna, S.R. 1973. Technical note: modelling urban air pollution. *Atmospheric Environment.* 7(1): 131–136.

Gilpin, A. 1980. *Environmental policy in Australia.* St. Lucia, Queensland, Australia: University of Queensland Press.

Goldsmith, J.R. and Friberg, L.T. 1977. Effects of air pollution on human health. In. Stern, A.C., ed. *Air pollution.* 3rd ed. New York: Academic Press. v.2. *The effects of air pollution:* 457–610.

Goldsworthy, L. 1978. Determination of influence of meteorological parameters upon sulphur dioxide concentrations over Newcastle. University of Newcastle. Thesis. Honours.

Guthrie, A. and Lamb, A. 1976. Ground level concentrations from power station emissions. *Clean Air.* 10: 25–32.

Hanna, S.R. 1971. A simple method of calculating dispersion from urban sources. *Journal of the Air Pollution Control Association.* 21: 774–777.

Hanna, S.R. 1978. Diurnal variation of the stability factor in the simple ATDL urban dispersion model. *Journal of the Air Pollution Control Association.* 28(2): 147–150.

Hanna, S.R. and Gifford, F.A. 1977. *Application of the ATDL simple urban dispersion model to Frankfurt, West Germany.* Oak Ridge, Tennessee: Atmospheric Turbulence and Diffusion Laboratory. (ATDL contribution no. 77/17).

Harris, S.F. and Ulph, A.M. 1977. *The economics of environmental services.* Canberra: Centre for Resource and Environmental Studies, Australian National University. (CRES general paper R/GP7).

Hawke, G.S. and others. 1978. Study of an oxidant day in Sydney. In. *Proceedings of the International Clean Air Congress, 1978 May, Brisbane, Australia.* Ann Arbor: Ann Arbor Science: 105–119.

Heck, W.N. and Brandt, C.S. 1977. Effects on vegetation: native, crops, forests. In. Stern, A.C., ed. *Air pollution.* 3rd ed. New York: Academic Press. v.2. *The effects of air pollution:* 157–229.

Hileman, B. 1981. Particulate matter: the inhalable variety. *Environmental Science and Technology.* 15(9): 983–986.

Horowitz, J. and Barakat, S. 1979. Statistical analysis of the maximum concentration of an air pollutant: effects of autocorrelation and non-stationarity. *Atmospheric Environment.* 13: 811–818.

Hyde, R. and others. 1981. *The Hunter Valley Meteorological Study*: interim report to the NSW State Pollution Control Commission.

Hyde, R. and others. 1982. *The Hunter Valley Meteorological Study.* Sydney: Macquarie University. School of Earth Sciences.

Irving, P.M. and Ballou, S.W. 1980. *SO_2 dose-response sensitivity classification data for crops and natural vegetation species.* Illinois, U.S.A.: Argonne National Laboratory.

Jacobsen, M. and others. 1970. New dust standards for British coal mines. *Nature.* 227(5257): 445–447.

Jacobsen, M. and others. 1971. The relation between pneumoconiosis and dust exposure in British coal mines. In. Walton, W.H., ed., *Inhaled particles III.* Old Woking, Surrey: Unwin: 903–917.

Jakeman, A.J. 1983. The role of recursive time series analysis in resource management. In. Wadhwa, L.C., ed. *Resource management: issues, techniques, applications.* Townsville: James Cook University of North Queensland: 223–245.

Jakeman, A.J. 1985a. Application of identification and system parameter estimation to environmental problems: some recent examples. In. Barker, H.A. and Young, P.C., eds. *Proceedings of the 7th IFAC Symposium on Identification and System Parameter Estimation, 1985 July 3–7, York.* Pergamon Press. v.1: 445–450.

Jakeman, A.J. 1985b. The status of technical requirements for environmental quality control policies. In. Jakeman, A.J., Day, D.G. and Dragun, A.K., eds. *Policies for environmental quality control.* Canberra: Centre for Resource and Environmental Studies, Australian National University: 22–55. (CRES monograph; 15).

Jakeman, A.J. and Simpson, R.W. 1983. Monitoring and modeling air quality around industrial operations: a risk assessment approach. In. *Papers Australian Mining Industry Council Environmental Workshop, 1983 September 26–30, Hunter Valley.* Sydney: Australian Mining Industry Council: 50–67.

Jakeman, A.J. and Simpson, R.W. 1985. Assessment of air quality impacts from an elevated point source. *Journal of Environmental Management.* 20: 63–72.

Jakeman, A.J., Simpson, R. W., Butt, J.A. and Daly, N.J. 1985. The effect of atmospheric pollutant emissions in the upper Hunter region. Part l: analysis and modeling of sulphur dioxide. *Clean Air.* 9(1): 9–16.

Jakeman, A.J., Simpson, R.W. and Taylor, J.A. 1984. A simulation approach to assess air pollution from road transport. *IEEE Transactions on Systems, Man and Cybernetics.* SMC–14(5): 726–736.

Jakeman, A.J. and Taylor, J.A. 1985. A hybrid ATDL-gamma distribution model for predicting urban area source acid gas concentrations. *Atmospheric Environment.* 19: 1959–1967.

Jakeman, A.J., Taylor, J.A. and Simpson, R.W. 1984. An air quality modeling approach for environmental impact assessment, airshed management and pollution control policy. In. *Proceedings Simulation Society of Australia 6th Biennial Conference, 1984 August 13–15, University of Adelaide.* Adelaide: SSA Organising Committee: 65–72.

Jakeman, A.J., Taylor, J.A. and Simpson, R.W. In press. Modeling distributions for air pollutant concentrations Part II: estimation of the parameters of the lognormal, gamma, Weibull and exponential distributions. *Atmospheric Environment.*

Jakeman, A.J. and Young, P.C. 1980. Towards optimal modeling of translocation data from tracer studies. In. *Proceedings Simulation Society of Australia 4th Biennial Conference, 1980 August 27-29, Brisbane.* St. Lucia, Brisbane: SSA Convening Committee: 248–253.

James B. Croft and Associates. 1980. *Environmental impact statement for expansion of an aluminium smelter, Line III, Kurri Kurri, N.S.W.* Newcastle: James Croft and Associates. 4v. Prepared for Alcan Australia Ltd.

James, D., Chambers, A., Gilbert, A. and Wright, H. 1983. *An integrated energy-economic-environmental model for Australia.* North Ryde: Macquarie University. (Centre for Environmental and Urban Studies. Report; no.82).

James, D.E., Jansen, H.M.A. and Opschoor, J.B. 1978. *Economic approaches to environmental problems.* Amsterdam: Elsevier.

Jaworski, J.F. 1979. *Effects of lead in the environment—1978: quantitative aspects.* Ottawa: National Research Council of Canada.

Keech, D. 1983. Personal communication to Fergus Anckorn.

Lakhani, H. 1982. Air pollution control by economic incentives in the US: policy, problems and progress. *Environmental Management.* 6(1): 9–20.

Lamb, R.G. 1979. The effects of release height on material dispersion in the convective planetary boundary layer. In. *Fourth Symposium on Turbulence, Diffusion and Air Pollution, 1979 January 15-18, Reno, Nevada.* Boston, Mass: American Meteorological Society: 27–33.

Larsen, R.I. 1969. A new mathematical model of air pollutant concentration averaging time and frequency. *Journal of the Air Pollution Control Association.* 19: 24–30.

Larsen, R.I. 1971. *A mathematical model for relating air quality measurements to air quality standards.* Research Triangle Park, N.C.: U.S. Environmental Protection Agency. (Publication no. AP-89).

Larsen, R.I. 1973. Response. *Journal of the Air Pollution Control Association.* 23: 292.

Lave, L.B. and Seskin, E.P. 1977. *Air pollution and human health.* Baltimore: John Hopkins University for Resources for the Future.

Lunnon, P. 1984. An investigation of the influence of meteorology, industrial emissions and monitoring technique on acid gas levels in Newcastle. University of Newcastle. Thesis. ME.

Lyon, R.M. 1982. Auctions and alternative procedures for allocating pollution rights. *Land Economics.* 58(1): 16–32.

McColl, G.D. 1981. Measuring the benefits of environmental protection—an overview of recent US research into the benefits of air and water pollution abatement programs. In. *Costs and benefits of environment protection.* Canberra: Australian Government Publishing Service: 38–61.

McGuire, T. and Noll, K.E. 1971. Relationship between concentrations of atmospheric pollutants and averaging times. *Atmospheric Environment.* 5(5): 291–298.

MacNeill, J.W. 1981. Counting benefits and costs in the 1980's. In. *Costs and benefits of environment protection.* Canberra: Australian Government Publishing Service: 16–25.

McRae, J. and others. 1954. *Early morning inversions at Rathmines and Williamtown and their penetration by hot plumes assuming still air.* Bureau of Meteorology. (Working Paper 58/1937).

Mage, D.T. and Ott, W.R. 1978. Refinements of the lognormal probability model for analysis of aerometric data. *Journal of the Air Pollution Control Association.* 28(8): 796–798.

Mitchell, A. 1985. Personal communication.

Montgomery, D.W. 1972. Markets in licences and efficient pollution control programs. *Journal of Economic Theory.* 5(3): 395–418.

Montgomery, T.L. and others. 1973. A simplified technique used to evaluate atmospheric dispersion of emissions from large power plants. *Journal of the Air Pollution Control Association.* 23: 388–394.

Moore, V. 1982. SO_2 patterns in Newcastle. Presented at Symposium on SO_x and NO_x in the Hunter Environment, Board of Environmental Studies, University of Newcastle, 29 October 1982. Unpublished.

Morgan, M.G. and others. 1978. A probabilistic methodology for estimating air pollution health effects from coal-fired power plants. *Energy Systems and Policy.* 2: 287.

Morgan, M.G. and others. 1983. Technical uncertainty in quantitative policy analysis: a sulfur air pollution example. Pittsburg, PA: Department of Engineering and Public Policy, Carnegie—Mellon University. Private communication.

National Research Council. Committee on Biologic Effects of Atmospheric Pollutants. 1971a. *Airborne fluoride: report.* Washington, DC: National Academy of Sciences.

National Research Council. Committee on Biologic Effects of Atmospheric Pollutants. 1971b. *Biologic effects of atmospheric pollutants: fluorides.* Washington, DC: National Academy of Sciences.

National Research Council. Motor Vehicle Nitrogen Oxides Standard Committee. 1981. *NO_x emission controls for heavy-duty vehicles toward meeting a 1986 standard: final report.* Washington, DC: National Academy Press.

Natusch, D.F.S. and Wallace, J.R. 1974. Urban aerosol toxicity: the influence of particle size. *Science.* 186(4165): 695–699.

Neale, P.C. 1980. Intermittent control system: an analysis of its use at Mount Isa. Nathan, Queensland: Griffith University. Thesis. M. Phil.

Neustadter, H.E. and Sidik, S.M. 1974. On evaluating compliance with air pollution levels not to be exceeded more than once a year. *Journal of the Air Pollution Control Association.* 23: 291–292.

New South Wales. Commission of Inquiry pursuant to section 119 of the Environmental Planning and Assessment Act, 1979, into a development application. 1983. *Glendell Coal Mine: a proposed open cut coal mine in the vicinity of Ravensworth, Shire of Singleton.* Sydney: Government Printer. Chairman: Mr John Woodward.

New South Wales. State Pollution Control Commission. 1980a. *Air quality measurements in NSW: annual review.* Sydney: The Commission.

New South Wales. State Pollution Control Commission. 1980b. *Annual report for the year ended 30 June 1980.* Sydney: The Commission.

New South Wales. State Pollution Control Commission. 1980c. *Pollution control in the Hunter Valley with particular reference to aluminium smelting.* 2nd ed. Sydney: The Commission.

New South Wales. State Pollution Control Commission. 1982. *Quarterly report of air quality measurements in New South Wales.* Sydney: The Commission. 8(3).

New South Wales. State Pollution Control Commission. 1983. *Air pollution from coal mining and related developments.* Sydney: The Commission.

Noll, R.G. 1982. Implementing marketable emissions permits. *American Economic Review.* 7(2): 120–124.

Nriagu, J.O. 1978. Deteriorative effects of sulfur pollution on materials. In. Nriagu, J.O., ed. *Sulfur in the environment. Part II: ecological impacts.* New York: John Wiley and Sons: 1–59.

Ott, W.R. and Mage, D.T. 1981. Measuring air quality levels inexpensively at multiple locations by random sampling. *Journal of the Air Pollution Control Association.* 31(4): 365–369.

Pasquill, F. 1974. *Atmospheric diffusion.* 2nd ed. John Wiley.

Patel, N.R. 1973. Comment on a new mathematical model of air pollution concentrations. *Journal of the Air Pollution Control Association.* 23: 291–292.

Pearce, D. 1976. The limits of cost benefit analysis as a guide to environmental policy. *Kyklos.* 29(1): 97–112.

Ramsay, P.J. 1978. Industrial odours and community attitudes. Melbourne: Monash University. Thesis. Master of Environmental Science.

Reinert, R.A., Heagle, A.S. and Heck, W.W. 1975. Plant responses to pollutant combinations, In. Mudd, J.B. and Kozlowski, T.T., eds., *Responses of plants to air pollution.* New York: Academic Press: 159–177.

Rothwell, R., Hing, T.P. and Bridgman, H.A. 1984. *Effects of power stations on precipitation in the Hunter Valley. Project 690: 1984 progress report.* National Energy Research, Development and Demonstration Program.

Rutledge, G.L. and Trevethan, S.L. 1980. Pollution statement and control expenditures 1972–1978. *Survey of Current Business.* 60(2): 27–33.

Saw, J. 1983. Estimates of emission loads from energy facilities for air quality planning in Australia. Unpublished manuscript.

Shoji, H. and Tsukatani, T. 1973. Statistical model of air pollutant concentrations and its application to air quality standards. *Atmospheric Environment.* 7(5): 485–501.

Simpson, R.W. 1984. Predicting frequency distributions for ozone, NO_2 and TSP from restricted data sets. *Atmospheric Environment.* 18(2): 353–360.

Simpson, R.W., Butt, J. and Jakeman, A.J. 1984. An averaging time model of SO_2 frequency distributions from a single point source. *Atmospheric Environment.* 18(6): 1115–1123.

Simpson, R.W., Daly, N.J. and Jakeman, A.J. 1983. The prediction of maximum air pollution concentrations for TSP and CO using Larsen's model and the ATDL model. *Atmospheric Environment.* 17(12): 2497–2503.

Simpson, R.W. and Hanna, S.R. 1981. *A review of deterministic urban air quality models for inert gases.* Silver Springs, Maryland: US. National Oceanic and Atmospheric Administration. Air Resources Laboratories. (NOAA. Technical memorandum ERL ARL—106).

Simpson, R.W. and Jakeman, A.J. 1984. A model for estimating the effects of fluctuations in long term meteorology on observed maximum acid gas levels. *Atmospheric Environment.* 18(8): 1633–1640.

Simpson, R.W., Jakeman, A.J. and Daly, N.J. 1985. The relationship between the ATDL model and the statistical distributions of wind speed and pollution data. *Atmospheric Environment.* 19(1): 75–82.

Sistla, G., Samson, P., Keenan, M. and Rao, S.T. 1979. A study of pollutant dispersion near highways. *Atmospheric Environment.* 13(5): 669–685.

Spear, R.C. 1970. The application of Kolmogorov-Renyi statistics to problems of parameter uncertainty in systems design. *International Journal of Control.* 11: 771–778.

Stern, A.C., ed. 1977. *Air pollution.* 3rd ed. New York: Academic Press. v.2. *The effects of air pollution.*

Surman, P.G., Simpson, R.W. and Stokoe, J. 1982. Application of Larsen's model to Brisbane, Australia. *Atmospheric Environment.* 16(11): 2609–2614.

Suttie, J.W. 1969. Air quality standards for the protection of farm animals from fluoride. *Journal of the Air Pollution Control Association.* 19: 239–247.

Taylor, H.S. 1982. Extractive continuous emissions monitoring at San Juan generator station. *Journal of the Air Pollution Control Association.* 32: 702–705.

Taylor, J.A., Jakeman, A.J. and Simpson, R.W. 1984. Nitrogen oxides from motor vehicles in Australia. *Search.* 15(7/8): 202–207.

Taylor, J.A., Jakeman, A.J. and Simpson, R.W. In press. Modeling distributions of air pollutant concentrations Part I: identification of statistical models. *Atmsopheric Environment.*

Taylor, J.A., Simpson, R.W. and Jakeman, A.J. 1985a. *A hybrid model for predicting the distribution of sulphur dioxide concentrations observed near elevated point sources.* Canberra: Centre for Resource and Environmental Studies, Australian National University. (CRES working paper 1985/16). Accepted for *Ecological Modelling.*

Taylor, J.A., Simpson, R.W. and Jakeman, A.J. 1985b. A hybrid model for predicting the distribution of pollutants dispersed from line sources. *Science of the Total Environment.* 46: 191–213.

Taylor, O.C., Thompson, C.R., Tingey, D. T. and Reinert, R.A. 1975. Oxides of nitrogen. In. Mudd, J.B. and Kozlowski, T.T., eds. *Responses of plants to air pollution.* New York: Academic Press: 121–139.

Tietenberg, T.H. 1980. Transferable discharge permits and the control of stationary source air pollution: a survey and synthesis. *Land Economics.* 56(4): 391–416.

Tingey, D.T. and Reinert, R.A. 1975. The effect of ozone and sulphur dioxide singly and in combination on plant growth. *Environmental Pollution.* 9(2): 117–125.

Turner, D.B. 1970. *Workbook of atmospheric dispersion estimates.* Research Triangle Park, NC: US. Environmental Protection Authority. Office of Air Programs. (Publication no. AP-26).

United States. Environmental Protection Agency. 1972. *Report to the President and Congress on noise.* Washington, DC: US. Government Printing Office: 1–36. (Senate document no.92–63).

United States. Environmental Protection Agency. 1977. *Compilation of air pollutant emission factors.* 3rd ed. Research Triangle Park, NC: The Agency. (USEPA publication no. AP-42).

United States. Environmental Protection Agency. 1978. *Noise: a health hazard.* Washington, DC: The Agency.

United States. Library of Congress. Environmental Policy Division. 1974. *A legislative history of the Clean Air Act amendments of 1970.* Washington, DC: US Government Printing Office.

Varshney, C.K. and Garg, J.K. 1979. Plant responses to sulfur dioxide pollution. *CRC Critical Review in Environmental Control.* 9(1): 27–49.

Venkatram, A. 1983. On dispersion in the convective boundary layer. *Atmospheric Environment.* 17: 529–533.

Whyte, A.V. and Burton, I., eds. 1980. *Environmental risk assessment.* Toronto: Wiley. (Scope report 15).

Wilcox, J. 1984. Personal communication.

Yocom, J.E. and Ulpham, J.B. 1977. Effects on economic materials and structures. In. Stern, A.C., ed. *Air pollution.* 3rd ed. New York: Academic Press. v.2. *The effects of air pollution:* 65–116.

Young, P.C. 1978. A general theory of modeling for badly defined systems. In. Vansteenkiste, G.C., ed. *Modeling, identification and control in environmental systems.* Amsterdam: North Holland: 103–135.

Young, P.C. 1982a. Systems methods in the evaluation of environmental pollution problems. In. Harrison, R.M., ed. *Pollution: causes, effects and control.* London: Royal Society of Chemistry.

Young, P.C. 1982b. The validity and credibility of models for badly defined systems. In. Beck, M.B. and van Stratten, G., eds. *Uncertainty and forecasting of water quality.* Oxford: IIASA/Pergamon.

Zeronian, S.H. 1970. Reaction of cellulosic fabrics to air contaminated with sulphur dioxide. *Textile Research Journal.* 40(8): 695–698.

Zeronian, S.H., Alger, K.W., and Omaye, S.T. 1971. Reaction of fabrics made from synthetic fibres to air contaminated with NO_2, O_3 or SO_2. In. Englund, H.M. and Beery, W.T., eds. *Proceedings of the 2nd International Clean Air Conference, 1970 December 6-11, Washington.* New York: Academic Press: 468–476.

ABBREVIATIONS

ADR	Australian Design Rules
ATDL	Atmospheric Turbulence and Diffusion Laboratory
CO	Carbon Monoxide
CRES	Centre for Resource and Environmental Studies
DEP	Department of Environment and Planning, New South Wales
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
EPA	Environment Protection Authority of Victoria
GM	General Motors model for highway emissions
HIWAY	Standard USEPA model for highway emissions
NHMRC	National Health and Medical Research Council
NSW	New South Wales
NO	Nitric oxide
NO_2	Nitrogen dioxide
NO_x	Oxides of nitrogen (both NO and NO_2)
SCA	Smeared Concentration Approximation Model
SEPP	State Environment Protection Policy, Victoria
SO_2	Sulphur dioxide
SP	Suspended particulates
SPCC	State Pollution Control Commission, NSW
TSP	Total suspended particulates
TVA	Tennessee Valley Authority
US	United States
USEPA	US Environmental Protection Agency
VKT	Vehicle Kilometres Travelled

INDEX

Aberdeen 3
ABS
  see Australian Bureau of Statistics
acid gas 38, 139, 146-7, 162, 224, 244, 248
  Boolaroo 228
  Lake Macquarie, Maitland, Cessnock 228
  Newcastle area 10-11, 15, 30-1, 132-6, 140-5, 147-9, 167, 204, 209, 212-4, 226-7, 230, 234, 287, 289
  see also nitorgen oxides; sulphur oxides
acid rain 6
Adamstown monitoring station 133, 137, 227
ADR
  see Australian Design Rules (ADR)
Advisory Co-ordinating Committee 252
aesthetic problems 14, 35, 39, 41, 136
agriculture 5, 10, 102-3, 116, 225-6
  see also vegetation
air pollution management 193-219
airshed 285
  see also Newcastle, airshed
Alcan smelter, Kurri Kurri 3, 10, 16, 138, 153-4, 160-2, 162-4
aluminium smelters
  see smelters
amenity, loss of
  see disamenity
Andrew's Farm SO_2 monitoring station 83
animals 26, 160-3, 243
  see also cattle industry; sheep and wool industry
anti-pollution devices 251
area source emissions 212, 214, 287
ash 81
Atmosphere Turbulence and Diffusion Laboratory, USA (ATDL) 28, 140-1, 146, 148, 169-71, 179, 185, 187, 189, 213, 274, 285-8
Attorney-General (NSW) 254
auctioning of pollution permits
  see price incentives, marketing of pollution permits
Australian Bureau of Statistics 3
Australian Design Rules (ADR) 137, 176, 178

Bayswater power station 9, 81, 82, 104-5, 113-6, 118-9, 121, 126-8, 157, 204, 205, 208, 226, 234
'best practical means' philosophy 194-6, 204-6
blasting
  see coal mining industry, blasting
Boolaroo 31, 219, 227, 228
  monitoring station 134, 136
brickworks 218
Brisbane 30, 287
British standard 26

Broke 40, 41, 44, 45, 59, 61, 72, 78, 233
'bubble' concept 199–200, 212–3, 217, 236
  see also 'multi-bubble' concept
buffer zones 236
building materials 38, 103

Canada, standards 9, 99, 195, 200
Canberra 30, 147, 169, 187, 286, 287
carbon dioxide 81
carbon monoxide 16, 30, 137, 147, 150, 167, 170, 178–9, 187, 189, 205, 229, 240, 250, 286–7
cattle industry 5, 10, 163, 228, 235, 243
  see also animals; vegetation
cement kiln dusts 38, 243
censuses 3
Cessnock 3, 153, 159, 160–2, 235
chemicals industry 201
City Hall monitoring station 139–41, 147
Clean Air Act 1961 250–3
'Clean Air' legislation, Australian 194
coal mining industry 3, 5, 6, 39, 45, 50, 67, 133, 167, 200, 201, 209, 219, 225, 229
  blasting 214–5
  low sulphur coal 142
  open cut 3, 5, 8, 9, 11, 13, 14, 17, 35, 39, 40, 41, 126, 200, 206, 209, 214–6, 224, 234, 236, 239
  underground 26
coal washeries 10
Commissions of Inquiry 195, 254–5, 257
corrosion 38, 103, 243, 248
'cost-benefit' analysis of air pollution control 201–4, 209, 212, 215
CRES air quality model 140, 145–8, 224, 226–7, 229, 287–91

data bank 236
degradation, land
  see land degradation
demography 41, 43
Denman 3, 104, 121
Denman Road SO_2 monitoring station 83, 91, 106
Department of Environment and Planning
  see NSW Department of Environment and Planning
despoliation
  see land degradation
dichotomous hi-volume samplers 8, 39, 79, 233
diesel powered vehicles
  see motor vehicles, diesel powered
direct controls 194–6, 199, 210, 213
Director of Environment and Planning 254
disamenity, levels of 8, 41, 68, 70, 80, 216, 224, 227, 230–1, 233, 251
dose-damage information 211, 239–49
dry scrubbing 10
dust pollution 6, 8, 11, 13, 14, 24, 35–39, 41, 45, 58–9, 66–7, 69, 76, 79, 126, 200, 209, 227
  dustfall 17, 68, 74, 78, 80, 132, 136, 148–50, 214–6, 219, 224–5, 233, 236, 263–9
  see also cement kiln dusts; health, dust effect on

Ekman spiral 88
Electricity Commission
  see NSW Electricity Commission

electricity generation
  see power stations, thermal

emission factors
  see area source emissions; line source emissions; motor vehicles, exhaust emission; point source emissions

emission standards
  see point source emissions, emission standards

employment
  see unemployment

environmental attitude survey 8, 41–80, 225, 230, 258–62

environmental control and planning 250–7

environmental effects and problems 14, 41, 44, 50–66, 73, 76–8, 193, 198 209, 211, 218–9, 223, 225, 230–1
  see also environmental attitude survey

environmental impact assessment (EIA) 254–6

Environmental Impact Statements (EIS) 7, 81, 104, 114–5, 119–21, 127, 195, 206, 208, 226, 236, 254–7

Environmental Planning and Assessment Act 1979 209, 250, 252, 254, 257

Environmental Protection Authority, Victoria
  see Victoria, Environment Protection Authority

environmental survey questionnaire
  see environmental attitude survey

Eraring power station 9, 16, 153–4, 156–7, 159

Europe 169, 200

exhaust emission
  see motor vehicles, exhaust emission

exports 3, 5, 6, 12

Fern Bay monitoring station 138

fertiliser production 129, 218

fibres, man-made
  see textiles

flora and fauna
  see animals; vegetation

fisheries 5

fluorides 6, 9, 10, 11, 14, 81, 104–7, 114, 116, 129, 138–9, 153–4, 160–5, 217–9, 225, 228, 235–6, 240, 243, 249

forestry 5

gaseous pollutants
  see pollutants, gaseous

Gaussian line source model 283–4

Gaussian plume model 18, 30, 96, 99, 108, 109, 112, 117–8, 121, 159, 168–70, 195–6, 206

General Motors (GM) model 169, 171, 174, 179, 186–7, 189, 283–4

glassworks 218

Glendell 206

Glennies Creek 40
  SO_2 monitoring station 83, 84, 106, 274

GM model
  see General Motors (GM) model

government investment 194

health 8, 14, 17, 28, 31, 41, 67, 112, 136, 139, 150, 193–4, 202, 209, 225, 228, 233–4, 244–8
  dust effect on 15, 35, 36, 79
  lead toxicity 227, 246–7
  public 11, 187, 189, 223, 251
  standards 13, 35, 82, 100–2, 116, 126, 138
  see also names of countries eg Canada

  synergistic effect on 9, 79, 239, 249
  threshold levels 239–40
  see also National Health and Medical Research Council
Health Commission
  see NSW Health Commission
Health Department
  see NSW Department of health
heavy duty vehicles
  see motor vehicles, diesel powered
highway models 196
hi-volume samplers 39
  see also dichotomous hi-volume samplers
HIWAY model 170
Hunter River 3, 11, 121
hybrid model 287
hydrocarbons 6, 137, 205, 212, 240, 250

industrial pollution
  see major industrial sources of pollution
inflation 201
inversion conditions 15, 84, 108–9, 110, 112, 113, 118, 127–8, 157–8, 196, 204, 207, 234, 283
  see also subsidence inversion
iron and steel industry 5, 129, 209, 213, 217–8

Japan, standards 99, 118, 156, 195
Jerrys Plains 121
Joint Coal Board 3

Kalgoorlie, W.A. 116
KI method 245
Kooragang Island 161
Kurri Kurri
  see Alcan smelter, Kurri Kurri

Lake Macquarie 3, 134, 153, 157, 159, 209, 214, 235
Lake Munmorah 106
Land and Environment Act 1979 254
Land and Environment Court 195, 254–5
land degradation 6
Larsen model 170–1, 270–4, 287
lead 7, 15, 31, 136, 205, 217–9, 227, 236, 240, 246, 250
Leontief input-output models 209
licences
  see price incentives, licences
Liddell
  meteorological station 87, 89, 91, 117, 174
  power station 8, 9, 14, 81–99, 104–6, 108, 112, 114, 116, 119, 121, 126–8, 157, 196, 204, 225–6, 234, 274, 280–3
  SO_2 monitoring station 83, 93
  State Mine 83, 93
line source emissions 214, 287
Local Environmental Plans 255
Local Government Act 1919 253
Local Government Liaison Committee 253
Lochinvar, proposed smelter 10, 153, 159, 162–3, 229, 235
loss of amenity
  see disamenity, levels of

McInerny's Farm So_2 monitoring station 83, 99, 104, 106
Maison Dieu 41, 43, 44, 45, 50, 55, 58, 59, 61, 62, 64, 65, 66, 68, 72, 74, 76–80, 224, 233
Maitland 3, 11, 16, 153, 159, 167, 174, 178, 186, 189, 229, 235
major industrial sources of pollution 153–165, 227
Maritime Services Act 1935 253

Maritime Services Board 253
marketing of pollution permits
  see price incentives, marketing of pollution permits
materials, damage to 15, 17, 31, 35, 82, 103–4, 116, 160, 223, 225, 227, 239, 243–4
  see also building materials; corrosion; paint; textiles
mathematical models 279–86
  see also names of mathematical models e.g. Gaussian plume model
metal corrosion
  see corrosion
meteorological regimes 13, 16, 17, 26, 32, 39, 95, 96, 116, 133, 148–9, 162–3, 199, 206, 213, 215, 217, 226, 230, 234
  changes 129, 139–42, 144–5, 151, 193, 212
  data 82, 87, 89, 93, 173, 208, 233
  stations 84, 174
Metropolitan Waste Disposal Authority 253
Metropolitan Water, Sewerage and Drainage Act 1938 253
Metropolitan Water, Sewerage and Drainage Board 253
Minister for Planning and Environment 254–5, 257
mobile sources of pollution
  see motor vehicles
monitoring stations 194–5, 199, 256
  see also names of stations e.g. City Hall
  air pollution, Newcastle 132–9, 151, 156, 194–5
  see also p. 130 for names and types of stations
  SO_2
  see p. 85 for names of stations
Monte-Carlo simulation 168, 172–3
moral suasion 194
motor vehicles 10, 11, 16, 41, 45, 61, 66, 67, 70, 72–5, 136–7, 149–50, 167–89, 214, 227, 229, 235, 239
  diesel powered 178–9
  exhaust emission 176–189, 250
Mt Arthur meteorological station 82, 87, 88, 89, 117
Mt Isa, Qld 116, 118, 126, 206, 280
Mounter St. monitoring station 139–41, 147, 290
'multi-bubble' concept 214
Munmorah power station 8, 16, 153, 158
Murrurundi 43, 45, 50, 55, 58, 59, 61, 71
Muswellbrook 3, 5, 11, 16, 81, 89, 104, 121, 167, 174, 178–9, 186, 189, 229, 234
  South 41, 43, 44, 59, 61, 62, 72, 78

National Health and Medical Research Council (NHMRC) 36, 39, 104, 137, 187, 205, 224, 227, 246, 251
National Parks and Wildlife Service 252
natural gas 227
Newcastle City 3, 5, 7, 10, 11, 15, 30, 31, 109, 129–51, 154, 167, 204, 209, 213, 226–7, 235, 239, 250, 270, 274, 287
  acid gas pollution 145, 159
  airshed 212, 219, 230
  Council 256
  surrounding area 108, 126, 149, 156, 234
NHMRC
  see National Health and Medical Research Council (NHMRC)
nitrogen dioxide 205, 234, 243–4, 248–9

nitrogen oxides 6, 9, 10, 11, 14, 16, 30, 38, 39, 67, 81–2, 104, 106, 114, 116, 126, 128, 133, 137, 159, 167, 170, 178–9, 185, 189, 212–3, 217–8, 223–4, 226–9, 233, 235, 240
  see also acid gas
Noise Control Act 1975 252–3
noise pollution 6, 8, 11, 14, 35, 39, 41, 45, 58, 59, 66, 67–72, 74–5, 77, 79, 233, 240, 245–6
Noxious Trades Act 1902 253
NSW Department of Environment and Planning 17, 195, 204, 233, 250, 252–4, 256
NSW Department of Health 64, 251
NSW Department of Public Works 252
NSW Department of Transport 252
NSW Electricity Commission 6, 39, 66, 81–4, 94, 104–6, 108, 114, 153, 156, 174, 209, 256
NSW Health Commission 251
NSW Station Pollution Control Commission 6, 7, 8, 17, 31, 35, 39, 40, 64, 129, 140, 165, 178, 194, 204–5, 214, 224, 233, 250, 252, 256, 273
  data supplied 82, 84, 108, 144
  dustfall 68, 79, 136
  guidelines 32, 106, 133, 160–2, 195, 227–8, 240, 251
  monitoring 15, 132, 138, 196, 199
  Technical Advisory Committee 252–3
NSW State Transport Study Group 173–4

odours 250
OECD Environment Directorate 201
offsetting
  see 'bubble concept'
oil burning, industrial 227
open-burning control 250
open cut coal mines
  see coal mining industry, open cut
ore handling 129
overburden removal 214
ozone 7, 133, 137, 167, 189, 227, 240, 245, 249

paint 103
'Pareto improvement' in welfare 202
particulate pollution 6, 8, 9, 14, 36, 39–40, 67, 100–2, 104–6, 116, 129, 159, 202, 204–5, 209, 212, 217–8, 223–7, 235, 240, 243, 248
  see also ash; dust pollution; lead; suspended particulates (SP); total suspended particulates (TSP)
petrol, lead content 250
petroleum industry 201
photochemical oxidants 7, 137, 170, 205, 212, 234
physico-chemical transport systems 24
Planning and Conservation Authorities 252
point source emissions 9, 16, 30, 40, 81–99, 105, 106, 113–26, 139, 145, 149, 156, 193–6, 206, 211–4, 217–9, 236, 274, 279, 287
  see also environmental control and planning; price incentives
  emission standards 250
  see also standards of NHMRC, and Britain, Canada, Japan, USEPA, West Germany, WHO
Pokolbin 160

policies on air pollution
  see air pollution management; direct controls; government investment; moral suasion; price incentives
pollutants, gaseous
  see names of gaseous pollutants eg nitrogen oxides; sulphur oxides
'polluter pays' principle 199
pollution permits 198–201
  see also price incentives, licences
Ponds Creek 119, 121, 127, 226
power stations, thermal 5, 8, 9, 14, 16, 67, 106, 118, 129, 153, 156, 162, 204, 209, 214, 217, 228, 234, 239
  see also names of power stations, Bayswater, Eraring, Liddell, Munmorah, Wangi; names of sites, Ponds Creek, Upper Saddlers Creek, Whites Creek
  future possible 15, 23, 82, 113, 119–21, 127, 235, 239, 255
Prevention of Oil Pollution in Navigable Waters Act 1960 253
price incentives 194, 198–201, 210–19, 235
  emission subsidies 198–201
  emission taxes 198–201, 210, 213–4, 216, 217–9, 236
  licences 214, 219, 236, 251
  marketing of pollution permits 198, 200–202, 211–12, 214, 215, 235
  transferrable rights 200, 211, 213
  see also 'best practical means' philosophy; cost-benefit analysis
primary industries
  see rural sector
productivity 201, 203
public health
  see health, public
Public Health Act 1902 253
Public Works Department
  see NSW Department of Public Works

quality of life 41, 43–50
questionnaire
  see environmental attitude survey

radiosonde balloon flights 109
rail transport 10, 63, 167–8
Ravensworth 40, 41, 43, 44, 45, 50, 59, 62, 64, 65, 66, 68, 72, 74, 76, 77–80, 224–6, 233
Ravensworth Farm SO_2 monitoring station 83, 91, 99, 106
Raymond Terrace 161
Regional Environmental Plans 255
risk assessment 19–32
road transport 11, 16, 63, 167–89
  see also motor vehicles
roadways
  see motor vehicles
rural sector
  see agriculture; cattle industry; fisheries; forestry; sheep and wool industry; viticulture

Scone 3
SEPP
  see Victoria, State Environment Protection Policy (SEPP)
sheep and wool industry 5, 10, 102–3, 163, 228, 235, 243
  see also animals; vegetation
Singleton 3, 5, 11, 16, 40, 89, 104, 121, 167, 174, 178–9, 186, 189, 229, 234

smeared concentration approximation (SCA) model 159, 160
smelters 6, 10, 11, 129, 204, 209, 217–9, 228–9, 235, 239
  see also Lochinvar proposed smelter; names of smelters, Alcan and Tomago
smog
  see photochemical oxidants
South Muswellbrook
  see Muswellbrook, South
SPCC
  see NSW State Pollution Control Commission
stacks 212
  height and design 9, 81–2, 105, 108, 114, 126, 156, 195, 199
standards
  see health, standards; point source emissions, emission standards
State Environmental Planning Policies 255
State Mine
  see Liddell, State Mine
State Pollution Control Act 1970 250
State Pollution Control Commission
  see NSW State Pollution Control Commission
statistical models 270–78, 287
  see also names of statistical models eg Larsen model
steel industry
  see iron and steel industry
Stockton monitoring station 138
subsidence inversion 10
subsidies
  see price incentives, emission subsidies
Sulphide Corporation 218
sulphur dioxide 6, 14, 30, 31, 67, 81–2, 100–6, 108, 110, 114–121, 127, 146, 149, 153–4, 217–8, 223, 228, 243
  effects on health 202, 248
  measurement 84, 86, 102, 151, 156–9, 206, 230, 233–5, 240, 270, 274, 282
  standards 100, 225–6, 272
  synergistic effects 11, 79, 204, 209, 224, 249
  trapping 112
  wet scrubbing 126, 218
    see also acid gas
sulphur oxides 9, 10, 38, 39, 129, 140, 205, 227
suspended particulates (SP) 100–2, 106, 116, 126, 133, 205, 209, 225–7, 233
  see also particulate pollution; total suspended particulates (TSP)
Sweden 245
Sydney 250
synergistic effects 9, 11, 31, 32, 38, 39, 79, 189, 204, 209, 223–4, 239, 248–9

taxes
  see price incentives, emission taxes
Technical Advisory Committee
  see NSW State Pollution Control Commission, Technical Advisory Committee
Tennessee Valley Authority (TVA) 109, 118
textile industry 201
textiles 103–4
threshold
  see dose-damage information; health, threshold levels
Tomago aluminium smelter 10, 16, 139, 153–4, 160–2, 164–5, 228
total suspended particulates (TSP) 28, 35, 36, 132, 134, 136, 147–51, 171, 223, 227, 287

see also particulate pollution; suspended particulates (SP)
traffic counts 174, 285
transport 6, 10, 11, 21, 35, 229
  see also motor vehicles; rail transport; road transport
transport of air pollutants 26, 28, 214
Transport Department
  see NSW Department of Transport
trapping conditions 108, 110, 112, 118–9, 121, 126–7, 159, 196, 226, 234, 283
trucks
  see motor vehicles

unemployment 6, 201, 203, 209, 219
United Kingdom standards and controls 195
University of New South Wales 6
Upper Saddlers Creek 119, 121, 127, 226
USA 169, 200, 201–2, 214, 218, 224, 229, 245, 286
US Clean Air Act 20
US Clean Air Scientific Advisory Committee 36
US Council of Environmental Quality 202
US Environmental Protection Agency (USEPA) 31, 35, 38, 39, 106, 118, 126, 156, 170, 196, 199–200, 205–7, 217, 224–5, 227, 240, 251
US standards 10, 11, 20, 35, 36, 99, 157, 179, 187, 189, 223

Vales Point power stations (A&B) 8, 16, 153, 157
vegetables 103, 163
  see also vegetation
vegetation 9, 15, 17, 26, 31, 35, 36, 38, 82, 102–3, 106, 160–5, 225, 227–8, 235, 239–49
vehicle emissions 11
Victoria
  Environment Protection Authority (EPA) 195, 201, 204, 210, 256–7
  standards and controls 195–6
  State Environment Protection Policy (SEPP) 195
viticulture 5, 103, 160–2, 164
  see also vegetation

Wangi power stations (A&B) 8, 16, 153
Warkworth 40, 41, 43, 44, 45, 50, 59, 61, 65, 72, 77–9, 224
washeries
  see coal washeries
Waste Disposal 252
Waste Disposal Act 1970 253
Watt St monitoring station 139–42, 145, 147, 270, 289–90
West Germany, standards 99, 156–7, 195
Western Australian vineyards 160
wet scrubbing 126, 218
Whites Creek 119, 121, 127, 226
WHO
  see World Health Organisation (WHO) standards
Williamtown 10, 84, 108, 109, 110, 126, 139–40, 145, 148, 158, 226
'willingness to pay' approach 201–2
wind conditions 9, 26, 28, 40, 84, 87–93, 97–8, 105, 110, 112, 114–7, 119, 121, 140, 170–5, 179, 185, 214, 229, 281, 284–6, 288
  see also windshear
windshear 118
Wollongong 250
World Health Organisation (WHO) standards 118, 129, 132–7, 146, 148, 150, 205, 224, 251, 272–3

The air pollution effects of large scale resource developments in Australia have always been difficult to assess. Forecasts are usually vague and uncertain. The Centre for Resource and Environmental Studies (CRES) at the Australian National University has completed a comprehensive analysis of the major problems involved in the development of the resources of the Hunter Region in New South Wales. One such problem is air pollution from widespread coal mining and industrialisation. In this book Dr Tony Jakeman and Dr Rod Simpson have analysed available air quality data and modelled possible effects. They detail the problems of air quality management which arise from the paucity of information and the natural randomness of airshed behaviour. They adopt a risk assessment framework which highlights the inadequacy of present air quality management. The book also sets out policy options for the future development of the region.

ISBN 0 86740 150 8
ISSN 0 725-3400