THE KWINANA AIR MODELLING STUDY

Summary Report

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Front Cover: Kwinana industry with Wattleup and Thompson Lake in the background.

Back Cover: Kwinana industrial strip looking south.

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A study promoted by the

Department of Conservation and Environment

and the

Department of Public Health

in co-operation with the

Commonwealth Bureau of Meteorology
State Energy Commission of Western Australia
Western Australian Institute of Technology
Murdoch University
University of Western Australia
and Kwinana Industry.

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INTRODUCTION

About This Pamphlet

A major air pollution study undertaken over a period of six years at Kwinana in Western Australia is described in detail in *The Kwinana Air Modelling Study,* Department of Conservation and Environment, Report 10, 1982, and a series of 24 accompanying reports. This pamphlet is a summary of the Kwinana Air Modelling Study (KAMS), conducted jointly by the Department of Conservation and Environment, the Department of Public Health and other institutions. It considers the nature of air pollution at Kwinana, describes the study and presents its major findings and recommendations.

The information in this pamphlet is designed to be of value to industry, individuals, local government authorities and government departments.

Why Kwinana?

The Kwinana industrial zone, located within 30 km of Perth, commands the most extensive port, road and rail facilities for heavy industry in Western Australia. It also contains light industry and commercial activities.

Being close to several major residential areas it at once offers major employment, and the potential for conflict in maintenance of the environmental quality desired for the various land uses. The cost of under-utilising the region's development potential in diverse uses would be high. KAMS is a major step toward systematically developing that potential.

Photography—Stuart Chape

Residential development at Kwinana with industry in the background.

Origins

In 1974, the Coogee Air Pollution Study (CAPS) recommended that an area of land to the north of major industry at Kwinana was unsuitable for residential development as a result of the levels of air pollution it experienced. The Kwinana Air Modelling Study grew out of the need to determine the air pollution impact of industry at Kwinana on a wider scale, and built upon the earlier work of CAPS. As suggested by its name, KAMS was largely concerned with the development and use of mathematical models as tools to estimate air pollution impact and plan effectively.

How It Was Done

The study was undertaken as a co-operative exercise involving government agencies, academic institutions and Kwinana industry. A senior-level Policy Group was formed in 1976, with a Technical Working Group responsible for the broad technical direction of the study. Routine activities were carried out by a core group made up of officers from the Department of Conservation and Environment, the Department of Public Health and a part-time consultant from the School of Physics and Geosciences at the Western Australian Institute of Technology.

Photography—Stuart Chape

The heavy industry complex at Kwinana.

Although the major contributions to the study in terms of capital costs, manpower and technical support, were made by the Department of Conservation and Environment and the Department of Public Health, other groups made significant contributions. These were the Commonwealth Bureau of Meteorology, the State Energy Commission, the Western Australian Institute of Technology, Murdoch University, the University of Western Australia and Kwinana industry.

Land Use

The Kwinana industrial area is part of the South-West Corridor, defined by the Perth Metropolitan Region Scheme. Under the Scheme, land use zonings include urban, industrial, parks and recreation, and rural (See Figure 1).

- Heavy industry is concentrated at the northern end of the industrial zone. Major activities in this section involve the refining of oil and alumina, and power generation. Other heavy industry includes a fertiliser manufacturing complex, steelworks and nickel refinery.
- Residential areas are the major centres of Medina and Rockingham, with a smaller area at Wattleup, to the north-east. Apart from these three, no urban or urban deferred areas are zoned south of Thompson Lake.
- Rural zones abut industry in a number of places. The region is a major market gardening area, with some small hobby farms and mixed farms.
- Several parts are zoned for parks and recreation. While some are heavily used for water-based recreation, others are retained as open space, to minimise conflict between industrial and residential land uses.

In the Metropolitan Region Planning Authority's 1980 document, *A planning strategy for the South-West Corridor,* it was recommended that no further urban development be allowed in a large area surrounding Kwinana industry, subject to the results of KAMS. Thus, KAMS is important as a direct input to the planning process at state and local government level. Possible pollution abatement strategies are also important.

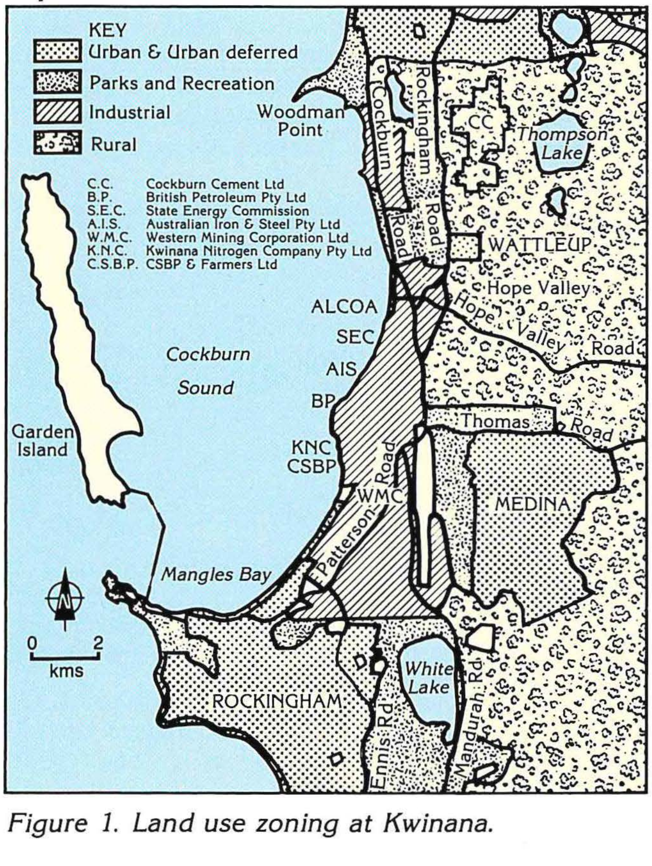


Figure 1. Land use zoning at Kwinana.

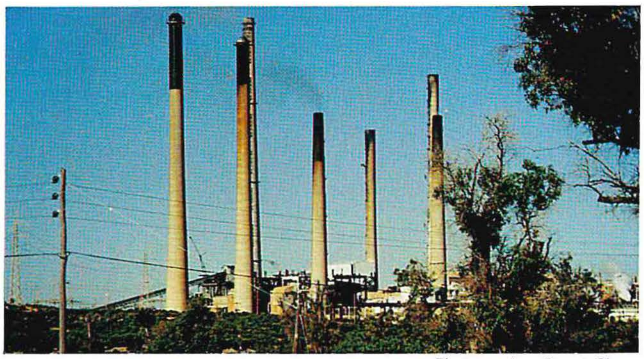
Air Pollution Climate

This term refers to the seasonal variations of air pollution levels in the region. It may be taken as the net effect of changes, through the year, of wind speed and direction, mixing depth (the maximum depth of air to which pollution may be dispersed from the surface), and of factors affecting the rate of plume dispersion. Briefly, for Kwinana:

- The general passage of high pressure systems to the south favours the dominance of easterly winds. These carry pollutants offshore, reducing the average pollution levels over land at Kwinana.
- On clear nights the surface temperature can fall below that of the air above, producing a nocturnal 'temperature inversion'. Pollutant plumes released into the air above the inversion remain warmer and lighter than the air below, and stay clear of the ground, again reducing ground level concentrations.

However, the easterly wind pattern is often disrupted:

- In winter, westerly winds associated with the passage of cold fronts transport pollution inland. Fortunately, they also bring large mixing depths, which dilute pollutants downwind, producing relatively low pollution levels.
- Summer easterlies are interrupted by sea breezes. Unlike the winter westerlies, sea breezes bring relatively small mixing depths, which reduce the dispersion of pollutants and lead to relatively high concentrations. These conditions are therefore of greatest importance to Kwinana's air pollution climate.



Photography—Stuart Chape

Tall industrial stacks at Kwinana.

Industrial Emissions

A wide range of air pollutants are emitted by Kwinana industry. Many are immediately obvious by their odour or their visibility as plumes.

However, analysis of industrial stack emissions has revealed that by far the most important pollutant emitted at Kwinana is sulphur dioxide. It is produced by the combustion of the sulphur-containing fuels oil and coal, by all major industries in the region. Typically, 150-200 tonnes of sulphur dioxide is emitted per day, major contributors being the petroleum refinery, alumina refinery and power station.

SULPHUR DIOXIDE

Sulphur dioxide is a colourless, pungent, irritating gas. Worldwide, about 60% is emitted by natural sources such as volcanoes and the oxidation of hydrogen sulphide by bacteria. Man-made sources arise mainly from the combustion of fossil fuels and from mineral processing.

Its Effects on Individuals

Sulphur dioxide is a highly water-soluble gas and consequently is readily absorbed in the moist passages of the nose and throat. It can be tasted at concentrations as low as 800 micrograms per cubic metre ($\mu g/m^3$), but an odour may not be noticed below 1300 $\mu g/m^3$. At slightly higher concentrations, irritation leads to increased airway resistance, the main effect being felt within a minute or two, with a slight further effect up to 15 minutes. Chronic cough and mucus secretion may result from repeated exposure.

In addition, the effects of sulphur dioxide on individuals who already suffer from respiratory disease, who are cigarette smokers or who are exposed simultaneously to other contaminants may be more severe.

In some cities of the northern hemisphere, sulphur dioxide occurs in association with high particulate concentrations. It is known that small aerosol particles can transport sulphur dioxide into the lungs and since moisture is often absorbed by these particles, the sulphur dioxide may dissolve to form sulphuric acid or sulphates. As a consequence, a three-to four-fold increase in the irritant response to sulphur dioxide is commonly observed in the presence of particulate matter. In the Kwinana district, particulate levels are low and therefore this effect is not significant.

Other Effects

Though sulphur is an essential nutrient for plant growth, high levels of sulphur dioxide in the atmosphere can severely damage trees and crops. Tests on a selection of Australian native species indicate that some woody species, including banksias and eucalypts, show sensitivity to sulphur dioxide.

Sulphur dioxide and its acid derivatives can cause corrosion of metals and deterioration of a wide range of materials including paint, concrete, building stone and natural and synthetic fibres.

Sulphur Dioxide Standards

Though it is generally accepted that air pollution affects human health, studies aimed at determining the degree of effect have not been unanimous in their findings. Interpretation of the results is made more difficult by the variation of such factors as time and frequency of exposure, age and medical history of the subjects, the extent of cigarette smoking and the effect of simultaneous exposure to other pollutants.

These studies have been used to indicate the lowest concentration of sulphur dioxide at which adverse health effects, such as increases in respiratory symptoms or respiratory disease incidence in the general population, might be expected. Where effects were demonstrable, it was difficult to determine whether they were related to extended exposures at moderate levels or more particularly to shorter-term high pollution episodes.

Ambient air quality criteria or standards are generally designed to protect health and are set at levels below which adverse effects have been observed. In the past, sulphur dioxide standards have been specified as a limiting average concentration over periods ranging from 24 hours to a year. Recently, there has been more concern with short-term air pollution episodes ranging from 30 minutes or less to a few hours, and standards have been set accordingly. With the exception of Victoria, statutory standards for sulphur dioxide have not been set in Australia but the National Health and Medical Research Council (NHMRC) has recommended the use of the 1972 WHO long-term goals. These are that the annual average concentration should not exceed 60 $\mu g/m^3$ and that 98% of the 24-hour average concentration observations should be below 200 $\mu g/m^3$ More recently the NHMRC has indicated that it is considering producing a 24-hour standard for Australian conditions.

In Western Australia, air quality matters are dealt with in the Clean Air Act which is administered by the Air Pollution Control Council (APCC). The Council is serviced by the Clean Air Section of the Department of Public Health which carries out the day-to-day application of the Act. There are no ambient air quality criteria for sulphur dioxide specified in the Clean Air Act although the NHMRC goals are used as guidelines in the State. The Department of Public Health has also recommended that, until standards are further developed in W.A., the 3-hour average USEPA standard of 1300 $\mu g/m^3$ should be used for short-term exposure to sulphur dioxide.

Whilst it was not within the scope of KAMS to set air quality standards, a number of existing criteria covering a wide range of averaging periods were used to assess the nature of air pollution at Kwinana. The most important used in the study are summarised in Table 1.

Table 1. Selected sulphur dioxide criteria for a range of averaging periods.

Annual average (WHO, 1979)	40-60 $\mu g/m^3$
(NHMRC, 1981)	60 $\mu g/m^3$
24-hour average (WHO, 1979)	100 - 150 $\mu g/m^3$
(Victorian EPA., 1982)	
'acceptable'	170 $\mu g/m^3$
'detrimental'	310 $\mu g/m^3$
3-hour average (US EPA., 1972)	1300 $\mu g/m^3$
1 -hour average (Victorian EPA., 1982)	
'acceptable'	500 $\mu g/m^3$
'detrimental'	1000 $\mu g/m^3$
'alert'	1400 $\mu g/m^3$

(Each of these should only be used within the particular provisions of their respective legislation or documents. The number of occasions that a level may be exceeded varies in each case).

THE STUDY PROGRAMME

The central goal of the study was to develop modelling techniques which would enable the formulation of an air quality management plan for Kwinana. This required measurements of the area's meteorology and air pollution, and the development of methods of using the meteorological data to represent measured air pollution levels and predict likely future levels under different conditions.

Continuous Field Monitoring

The estimation of air pollution levels requires most obviously the recording of the amount of pollution emitted. Major Kwinana industries co-operated in this important aspect of the study, providing a detailed record of their fuel usage. From these data, the rates of sulphur dioxide emission from more than 50 separate sources were catalogued, for use in modelling.

Many meteorological factors affect pollutant dispersion. As a result, wind was recorded alone at several sites, and along with temperature and solar radiation at two 'base stations'. Mixing depth was also measured continuously at one location. All data were logged on paper charts or magnetic tape, to be later processed and stored on computer records.

Daily average sulphur dioxide concentrations were measured at nine locations, and in addition, at the base stations, short-term variations were detected by recording 10-minute averages.

Photography—Shepherd Baker Studios

A KAMS base station.

Intensive Experiments

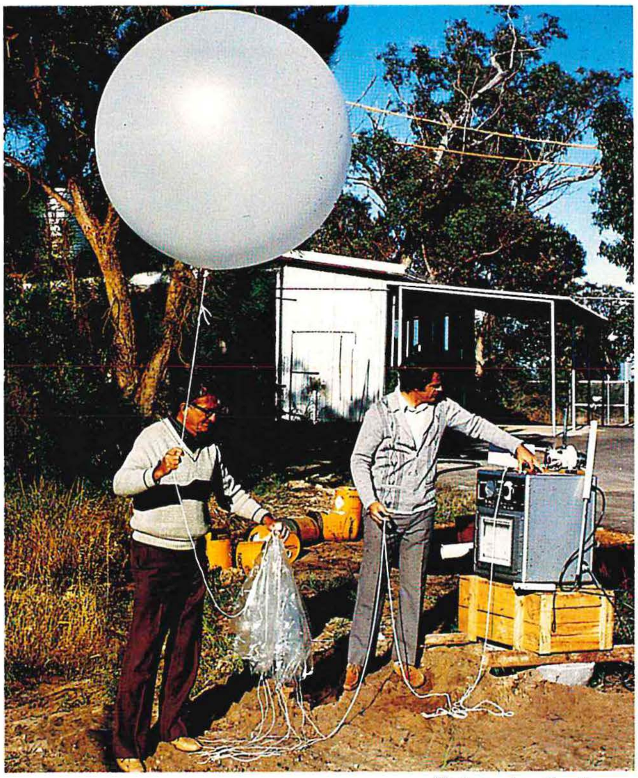
No meteorological monitoring programme can be relied upon unless measurements at the surface and processes at plume level are properly related and understood. Three experiments were conducted, so that these relations could be included in the models used.

Because of the importance of the sea breeze, two were organised on days when typical sea breezes occurred. Winds and temperatures at high levels were determined using balloon-borne instruments, and the dispersion of a tracer gas specially emitted from one chimney stack was measured. Results showed that conventional air pollution models were not accurate enough for the needs of KAMS, and also allowed rigorous testing of more sophisticated models developed during the study.

A further experiment was conducted in the early morning, when rapid changes in dispersion conditions can produce sudden increases of ground-level pollutant concentrations. Again, the results were used to test and calibrate the models.

Computer Modelling

If wind speed is doubled, the concentration of air pollutants should be halved if all other factors remain the same. An air pollution model uses mathematical formulae, combining principles such as this to give an estimate of the way pollution levels vary in a region under study.



Photography—Ken Rayner

Part of the KAMS experimental programme.

The application in this manner of the detailed data gathered during the study was only possible through the use of sophisticated computer programs. Such a program, often including a number of separate components, can be regarded as an 'air pollution model'.

Any model of pollutant dispersion must represent the mixing of polluted air into clean air by turbulence. This process can be modelled in various ways, and in KAMS two separate methods were used.

Turbulence is an essentially random phenomenon, so that no model can be expected to give exact results in all conditions. In any application at Kwinana, the more accurate of the two models was used in the derivation of the final results of the study.

The KAMS monitoring programmes and field experiments showed a number of important features of air pollution at Kwinana.

- Periods of significant air pollution occurred mainly in summer, and normally coincided with the sea breeze. The periods were relatively short, being generally less than three hours. (Figure 2).

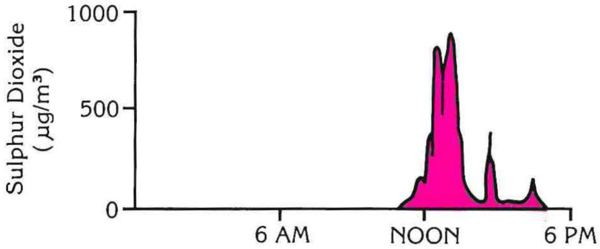


Figure 2. Variation of sulphur dioxide at Wattleup for a typical summers day.

- As a result, in analyses of the extent of the air pollution impact at Kwinana, it was necessary to study pollution episodes over time periods in the range from 1 to 3 hours (Table 2). Over this range, the 1-hour analyses detected more of the episodes.

- Thus, any evaluation of air pollution at Kwinana must include the impact of these short-term air pollution levels as well as medium- and long-term levels. The selection of the most appropriate air quality criteria will involve a compromise between short periods of relatively high levels, and lower medium- or long-term averages which may not be so objectionable but could have more important health implications.

Table 2. Sulphur dioxide concentrations measured at Wattleup.*

	1979	1980
Annual average, µg/m³	47	49
Number of 24-hour periods over:		
100 µg/m³	51	53
150 µg/m³	21	19
Number of 3-hour periods over:		
1300 µg/m³	3	0
Number of 1-hour periods over:		
500 µg/m³	259	251
1000 µg/m³	51	30
1400 µg/m³	12	2

*The levels chosen for reference are based on the criteria given in Table 1.

- Pollutant dispersal to ground level, within onshore flows, is often delayed by the slow growth inland of the mixing depth. For example, in the second intensive experiment, tracer gas was sampled at points downwind of a tall coastal stack. Rather than finding peak ground level concentrations at a normal distance of a kilometre or so, the experiment showed a peak five to six kilometres away. This means that short term sulphur dioxide concentrations inland may be increased, in comparison to those which might be expected if no sea breeze effect was present. (Figure 3).

Both of the KAMS models were applied to data for the year July 1979 to June 1980. Calculations by each model were compared to the air pollution record

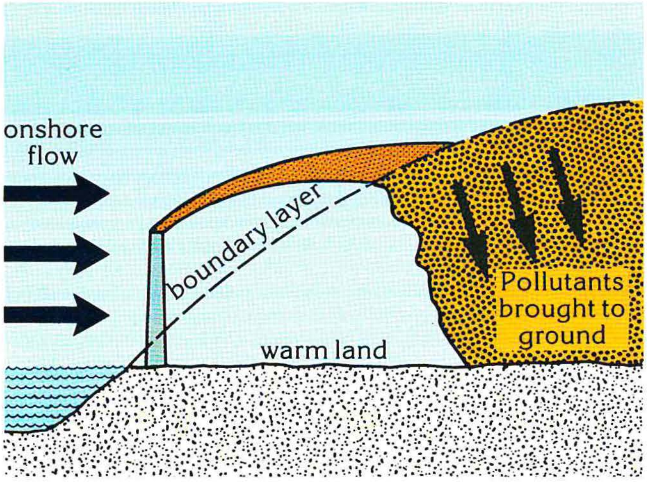


Figure 3. The production of high pollutant concentrations during onshore flows.

at Wattleup, and the more accurately validated calculations used to estimate air pollution impacts for the whole region. The most important conclusions from the modelling work are:

- Long-term average sulphur dioxide concentrations generally fall within accepted air quality objectives.

- Daily average concentrations over much of the study area fall within USEPA and Victorian standards, but exceed the WHO guidelines.

- The USEPA 3-hour standard is exceeded over a significant portion of the study area.

- The Victorian 1-hour objectives are exceeded over a large portion of the study area.

Though the characterisation of air quality at Kwinana is closely dependent upon the ambient criteria used for reference, the study has nevertheless indicated that the potential for problems is greatest as a result of short-term, relatively high concentration pollution episodes. As an illustration, Figure 4 shows the modelled number of occasions when the 1-hour average sulphur dioxide concentration exceeded 1000 µg/m³ for the year July 1979 to June 1980.

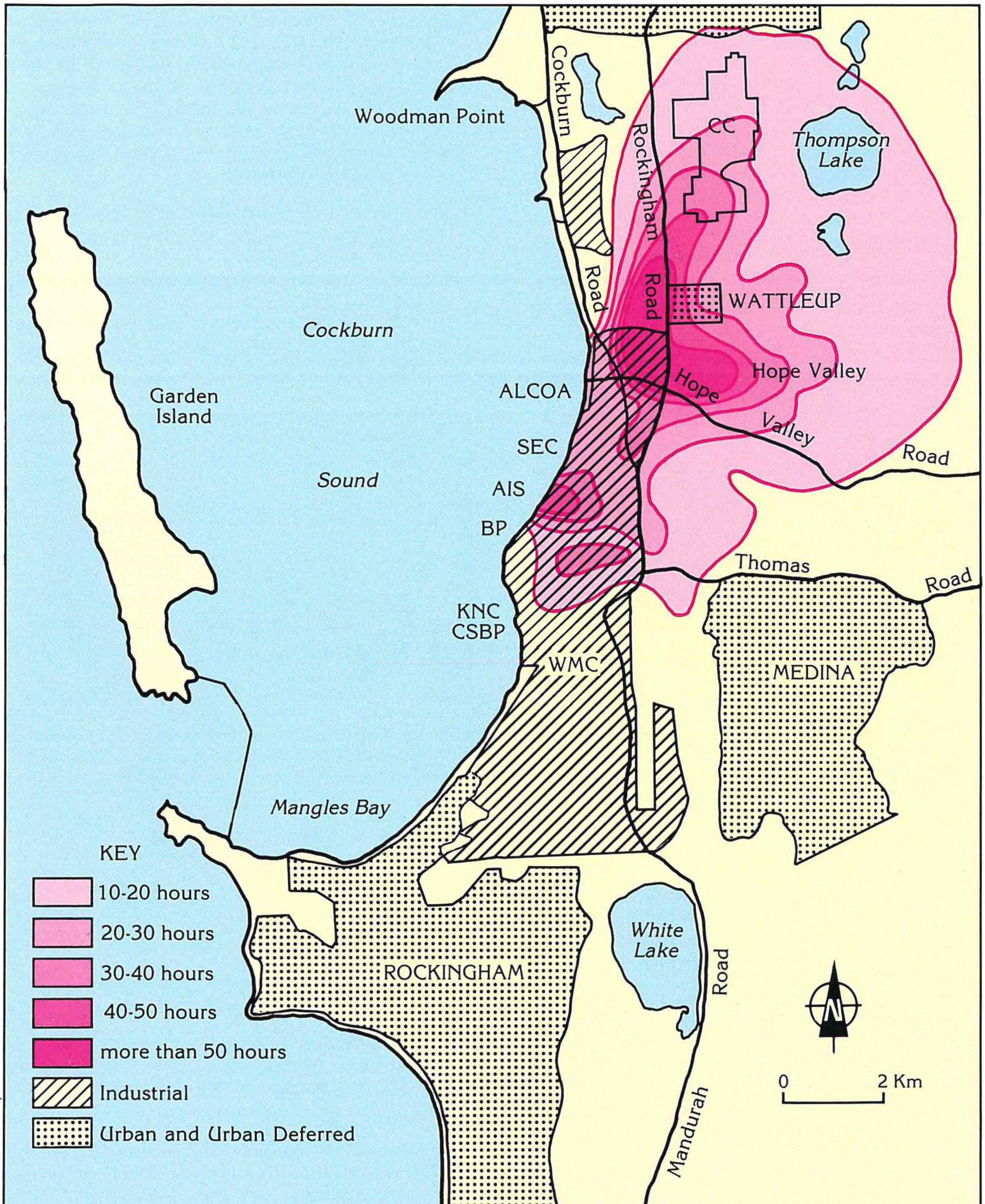


Figure 4. The number of 1-hour periods with concentration greater than 1000 $\mu g/m^3$ for the year July 1979 to June 1980.

WHAT SHOULD BE DONE?

The future of air quality in the Kwinana region will depend on the use made of the knowledge gained during KAMS.

To take advantage of the best options, a number of issues need to be addressed:

Immediate Priorities

- Because of the unusual short-term changes of air pollution levels in the area, it is recommended that the Air Pollution Control Council should adopt air quality objectives covering a range of averaging periods, corresponding to the timescales of air pollution problems encountered.

- Through use of the air quality objectives selected, emission controls and graded land use, air quality management should become an integral part of land use planning at Kwinana.

- It is recommended that the public be made aware of the extent of air pollution in areas surrounding Kwinana.

Longer-Term Trends

There are current prospects of some improvement in pollution levels, through changes such as:

- Changeover of the fuel used by the Alcoa refinery to natural gas, an almost sulphur-free fuel.

- Partial changeover by the SEC power station to the use of natural gas.

These will decrease the frequency with which relatively high pollution levels occur, but not ensure that all the criteria used for comparison in the study will be met over the whole study area.

- Because of the existing air pollution levels at Kwinana, no further large-scale residential development should be allowed in the area of the 'interim buffer zone' originally proposed by the Metropolitan Region Planning Authority in 1980. This policy should remain, even if there is a reduction of emission levels due to the use of natural gas, since there is a possibility of industry having to revert to high-sulphur fuels in the future.

- The changes to air pollution levels over the Medina residential area should be carefully studied if the introduction of heavy industry in the southern portion of the interim buffer zone is considered.

Air Quality Management Methods

- The modelling studies suggest the occurrence of short-term pollution episodes in the vicinity of Thompson Lake. The distance to this location from the sources is somewhat beyond the range of confident application of the air pollution models used in KAMS.

  This means that any development in this area must be preceded by detailed investigations, using short-term monitoring techniques as employed in this study.

- Changes to the use of low-pollution fuels or emission control strategies must be encouraged, at Kwinana.

- Periods of greatest concern at Kwinana are restricted primarily to summer afternoons. The Department of Public Health, on behalf of the Air Pollution Control Council, should discuss with major industries at Kwinana the feasibility of changes to industrial processes and fuel usage which would reduce air pollution impact during the times of major concern.

- The cost and effectiveness of the various options for air pollution management at Kwinana should be assessed systematically. Measures of possible benefit include the restriction of the use of fuel oil by the SEC power station to night and morning periods during the months of high pollution impact and the restriction of burning of excess gases by the BP refinery to within the same periods.

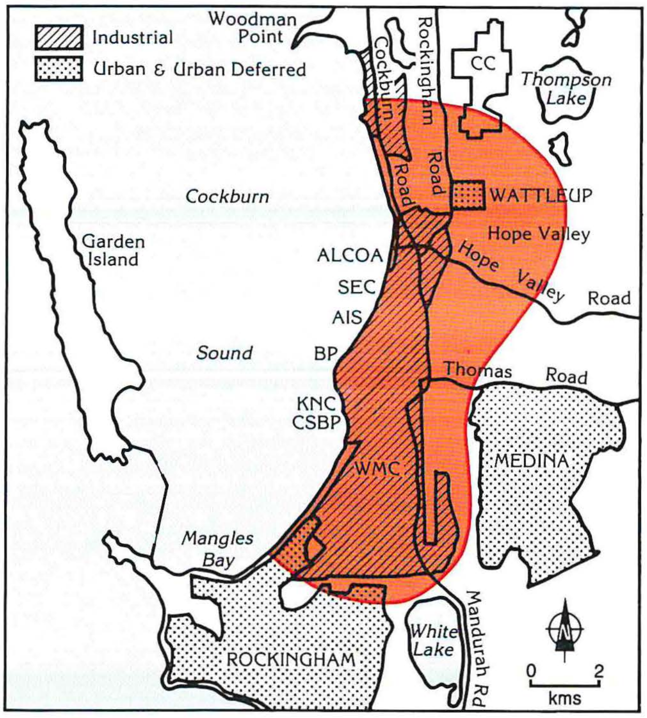


Figure 5. The 'interim buffer zone' at Kwinana.

- The attainment of any air quality objectives, through land use controls, or emission controls such as those above, involves costs which will have to be borne by the community.

In W.A., statutory responsibility for land use planning and clean air lies with state and local government planning authorities, and the Air Pollution Control Council (Department of Public Health) respectively. It is important that these bodies now take up the findings of the Kwinana Air Modelling Study, and apply them in a manner to the benefit of the whole community, recognising the needs of industry whilst protecting the health and welfare of the community at large.