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Two Air Pollution Problem Areas in Australia

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Introduction

Local and *global* air pollution problems are mostly due to the combustion of fossil fuels. Combustion of coal leads to the emission of so much sulfur dioxide that it is the pollutant of most concern *locally*. Australia emits a small but important fraction of the global SO_2(Table 1). Some of this is from tall stacks and may travel great distances. The 'greenhouse' problem and the potential for 'acid rain' is taken seriously in Australia. However, so far no removal of sulfur nor other gases from emissions is practiced.

Based on my own experiences, two problem areas concerning sulfur dioxide are discussed here.

The first is Kalgoorlie, a gold-mining city in Western Australia(see Fig. 1 for its location).

I have worked as an air pollution meteorologist/modelling consultant for the State Environment Protection Authority(EPA) of Western Australia and for the major industrial company there for several months.

The second is the Latrobe Valley(also shown in Fig. 1), the industrial centre of Victoria.

For 3½ years ending last year I directed a major air quality measurement and modelling study there. It was a joint study by the Victorian EPA and the State Electricity Commission.

Kalgoorlie

The major industries are gold and nickel mining. Roasting the sulfide ores to release

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the nickel and gold emits SO_2. A flowchart of the gold extraction process is given in Fig. 2.

The situation.

The city is 500 km from the west coast of Australia and has a population of 25,000. Three sulfide-ore roasters are immediately to the east of the city along a line called the 'golden mile'. This is shown in Fig. 3. A large nickel smelter is 12 km to the south.

The prevailing winds are easterly to southerly. They cause the plumes from the roasters to impact on the city much of the time. The worst conditions are in the early morning in light south-southeasterly(SSE) winds. Then the three roasters are in line with the wind. The SO_2-rich plumes from the roasters mix rapidly to the ground in the early-morning convective turbulence.

There are several stations monitoring SO_2 all the time. One is located at the Regional. Hospital—in line with the three roasters in SSE winds. One is at the Technical School, only 650 m west of the central roaster. And one is at South Boulder Primary School—near the largest roaster at the southern end of the golden mile. These are shown on Fig. 3.

Measured maximum 1-hour average SO_2 concentrations used to sometimes reach high levels. In a recent early-morning case a SO_2 monitor at the Hospital went off-scale for half an hour.

We do not know the impact on human health of these SO_2 levels in Kalgoorlie. However, vegetation damage has been observed. Some damage is downwind of the nickel smelter located to the south of the city.

Methods of control.

The roasters are licensed to emit a specified flux of SO_2 to air. They also have to ensure that the ambient ground level concentration does not exceed 1300 $\mu g/m^3$ when averaged over three hours. Australian standards are usually stricter, as may be judged from Table 2.

To meet the ambient air quality requirement, the roasters and the nickel smelter operate a reactive control strategy. This has been agreed to by the EPA. It is as follows :

> On the basis of extrapolated SO_2 measurements, if the 3 hour SO_2 level is predicted to exceed 1100 $\mu g/m^3$ at a monitoring station within the next hour the roasters upwind of that station are shut down and are kept closed for an hour after the extrapolated level has dropped below 1100 $\mu g/m^3$.

The strategy is successful : only two exceedences of 1000 $\mu g/m^3$(3 hour average) since July 1987 have been recorded at the Hospital monitor compared with 11 in 1984/85. One instance appears to have been due to the nickel smelter. However, the strategy does little to lessen brief impacts.

Also, it controls only at the receptors, not over the whole city. The EPA has recently decided that the strategy is no longer satisfactory : the whole city must be protected.

A predictive control strategy is thus required—one that forecasts what the impact will be for the next period on the basis of present meteorology and concentrations. If the prediction is for bad conditions the offending roasters would be temporarily shut down. Recently, I have been involved in developing such a strategy for Kalgoorlie using a simple mathematical model. It is not yet implemented.

The predictive control strategy.

A mathematical model is run in real time. It predicts the 10-minute or 1-hour(as required) ground level SO_2 concentrations on a grid of points all over the city for the next period, based on the current emissions from the roasters and the current meteorology of the region. If an SO_2 level greater than an acceptable value anywhere in the region is predicted, the responsible roaster is shut down before the value is reached. Operation restarts when it is predicted to be safe.

The model is a multi-source Gaussian plume model developed for the EPA of Victoria. It is similar to the Industrial Source Complex model of the USEPA. It has been extended to include recent scientific understanding of dispersion and plume rise.

I have tested the model using detailed meteorological and emissions date for all hours of 1984 for Kalgoorlie. A comparison of observed and predicted concentration frequency distributions for 1984 shows that the model is good.

The effect of the predictive strategy on the operations of the roasters has also been studied. On average, the roasters would be required to close down for about an hour a day. This is tolerable : it is what is typically required under the present reactive control strategy during the summer time. That is the season when the winds most frequently bring the plumes over Kalgoorlie.

The worst-case conditions for the gold roasters.

As an exercise, I have used model to predict a hypothetical maximum SO_2 concentrations at the Hospital. It is not clear whether these predictions would actually occur in practice. Guided by general experience, I took a range of wind speeds around 0.6 ms^{-1}, wind directions around 133°, and a range of turbulence levels about the most probable moderately unstable mixing conditions. All three roasters were assumed to be operating at licence conditions. The results are presented here in Fig. 4.

The sensitivity of predicted SO_2 concentration at the Hospital to changes in mixing height is particularly interesting. Before sunrise, when the mixing height would be below 160 m, the model predicts no impact on the Hospital. All the plumes would pass overhead and not mix to the ground until further away. A secondary maximum would occur as the mixing height grows to 190 m in response to morning sunshine. This maximum would be due to the combined impact of the nearer two roasters. It is not until later in the morning when the mixing height reaches to 290 m that the third, largest, roaster plume is predicted to impact there. Then the predicted extreme value of 5960 $\mu g/m^3$ is reached. This is well above the maximum measuring value of the monitors used in Kalgoorlie. At still higher mixing heights the ground level concentration is predicted to decrease, due to mixing of the plumes into a greater volume.

The longer-term solution.

While a strategy of temporarily closing roasters is beneficial it is no real solution for the city as a whole. If roasting of the gold-bearing ore continues the only solutions are removal of SO_2 from the emissions—not economically feasible—or relocation of the roasters.

In fact the roasters are being relocated : they are to move to a new site 15 km north of the city in the next three years. Northerly winds are rare so the impact of the SO_2 emissions on the city will be small. There will still be a need to forecast effects on the city day by day, and to control for vegetation damage in the vicinity of the plant. A shutdown strategy—probably predictive—will be employed at the new site.

The Latrobe Valley

This is where 70% of the electricity production for Victoria occurs. 6000 MW are produced by combustion of brown coal in five power stations.

The situation.

As is shown in Fig. 5 the Valley runs east-west—in line with the prevailing winds. There are mountains to the north and south. The sea is to the south and east. The city of Melbourne is 150 km to the west.

In 1984 the total SO_2 emission into the Latrobe Valley was 44000 tonne(Table 1). The emissions inventory is shown in Fig. 6 as a function of chimney height. This emphasises the vertical separation of urban and industrial emissions. The latter are mostly coal-combustion emissions from tall stacks(80 to 260 m high).

The existing air quality is generally good. There are only minor air pollution problems with SO_2, O_3 and fine particles. However, several years ago, plans for a major industrial expansion led to concern about the air quality in the Latrobe Valley. There was a need to investigate how it would change over the decades.

Methods of control.

As for other regions of Australia, a licence to emit must be obtained. In Victoria, emission limits and ambient air quality objectives(Table 2) must be met on the basis of model calculations. This is different to Kalgoorlie.

The Latrobe Valley study was designed to provide data on existing conditions and to forecast likely conditions into the future for planning purposes for the whole region. Regional planning gives an extra degree of flexibility for siting industry, modification of processes, imposition of new emissions control devices, etc. This is not so easily done case by case or with an established situation.

The rôle of mathematical modelling.

Several air quality prediction models were developed by the Latrobe Valley study, each for a different purpose. The most important for planning work is the same Gaussian plume model already mentioned in regard to Kalgoorlie. It is used to predict the existing and future levels of SO_2 using as input all known emissions in the region : there are hundreds of minor sources and over 20 major sources. The 1-hour SO_2 levels at many sites are computed for a whole year of meteorological data. The predictions for the existing situation have been tested by comparison with extensive monitoring results also obtained by the study.

This model is also used to predict the frequency of occurrence of various levels of fine particles in the air.

For more difficult tasks, such as for modelling ozone, we use models which move 'puffs' around the region in response to changing winds. Or we use a 'prognostic' model(like that used by the national weather service) to compute solutions to the fundamental equations of conservation of mass, momentum and energy on a grid of points moment by moment. However, the 'prognostic' model is expensive to run and so its use is restricted to special studies.

Planning for the future.

Results from the Gaussian plume model for the years 1984 and 2005 for SO_2 are discussed here. For planning work we are only interested in the frequency of occurrence of the higher pollutant concentrations. In Victoria we test the 1-hour average concentration at the 99.9% annual frequency level against air quality objectives or standards. This means that we require that the 9th highest SO_2 concentration out of the 8544 predictions is less than a specified value(given in Table 2) before a proposed emission is acceptable.

Results for 1984 are shown in Fig. 7. The predictions of the 9th highest 1-hour average SO_2 concentration compare well with the observations made at fourteen scattered monitoring sites throughout the Latrobe Valley. There are some discrepancies but these are minor.

Model predictions for 2005(also shown in Fig. 7) have caused concern in the region and may lead to a change of development strategy. These predictions are based on a projected four-fold increase in the emissions of SO_2 due to increased coal use. The predictions show that the region will experience problems due to plumes striking the mountain parks in the south of the Valley, as represented by the new station 15 in Fig. 7. There will also be problems. due to plumes mixing to the ground in mid-morning close to some of the power stations on hot days – station 5 in Fig. 7.

It is too early to say how much impact the modelling work will have on development in the Latrobe Valley region. It has been important already, having heightened debate greatly. Of course the modelling tools developed by the Latrobe Valley study will be used to explore alternative strategies as these are proposed.

The longer-term situation.

There is some expectation that acid deposition may be important in the Latrobe Valley with larger SO_2 emissions. An investigation is now underway. Desulfurization of the stack gases is a possibility, but would be very expensive.

The Australian government has a program of encouraging energy conservation and the use of alternative energy sources. However, there is strong opposition to the use of nuclear energy and other sources are scarce.

Conclusion

A range of strategies is required to control air pollution. Mathematical models in which the consequences for local air quality can be explored by relating emissions to ambient air pollutant concentrations, are an important tool for management. They do require, however, much information about emissions and meteorology up to plume heights that is frequently unavailable. The examples discussed here have had sufficient data to enable different strategies to be explored.

Australia(and perhaps Korea) should be more concerned about the *global* consequences of man-made emissions when considering *local* air quality. The greenhouse effect and the impact of the Antarctic ozone hole are consequences of air pollution that will be with us for a long time.

Acknowledgements

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Table 1. Emissions of SO_2 for selected countries (1985)
(caused by man-kilotonne per year)

U.S.A.		21100
U.S.S.R.		11100
United Kingdom		3540
Korea		1226
Sweden		272
Australia		1520
(Maior Extractive	1100)	
(Thermal Power	260)	
Kalgoorlie	372	
Latrobe Valley	44	

Table 2. Maximum permissible levels of SO_2 in ambient air

NHMRC Guidelines(Australia) :			
annual mean		60 μg/m³	
1 hr ave.		700 μg/m³	
10 min ave.		1400 μg/m³	
Victorian EPA(The SEPP) :			
1 hr ave.	Acceptable		0.17 ppm (460 μg/m³)
	Detrimental		0.34 ppm (920 μg/m³)
	Alert		0.50 ppm (1360 μg/m³)
24 hr ave.	Acceptable		0.06 ppm (160 μg/m³)
	Detrimental		0.11 ppm (300 μg/m³)
W. H. O. :			
24 hr ave.		100~150 μg/m³	
annual mean		40~ 60 μg/m³	
USEPA (Secondary standards) :			
3 hr ave.		1300 μg/m³	
24 hr ave.		270 μg/m³	
annual mean		55 μg/m³	
KOREA :			
24 hr ave.		0.15 ppm (406 μg/m³)	
annual mean		0.05 ppm (135 μg/m³)	

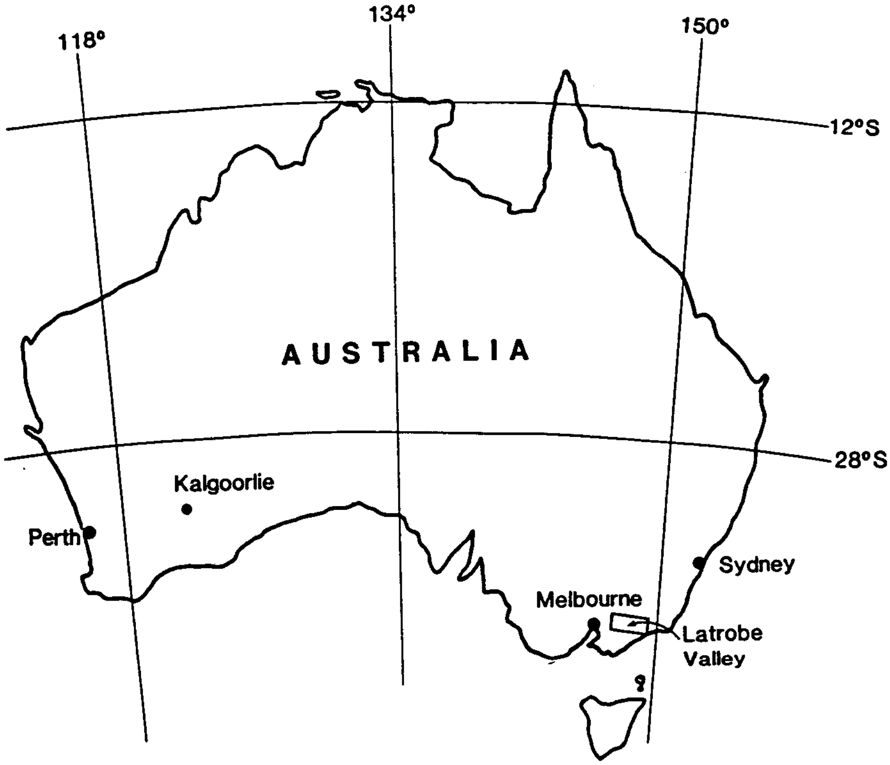

Figure 1. Locations of Kalgoorlie and Latrobe Valley in Australia.

Ore
↓ →mullock heaps
FeS (26% Fe, 30% S, 40~80 g/tonne Au)
↓ ←air roasting
$Fe_mO_n + SO_2$ (60% = 600 kg/tonne) ↑
→ ↓ ←calcium cyanide + ……
Au-CN complexes
↓
filter →slime dumps
↓ ←zinc+ ……
└GOLD+ ……on carbon blocks

Figure 2. Gold extraction process used at Kalgoorlie.

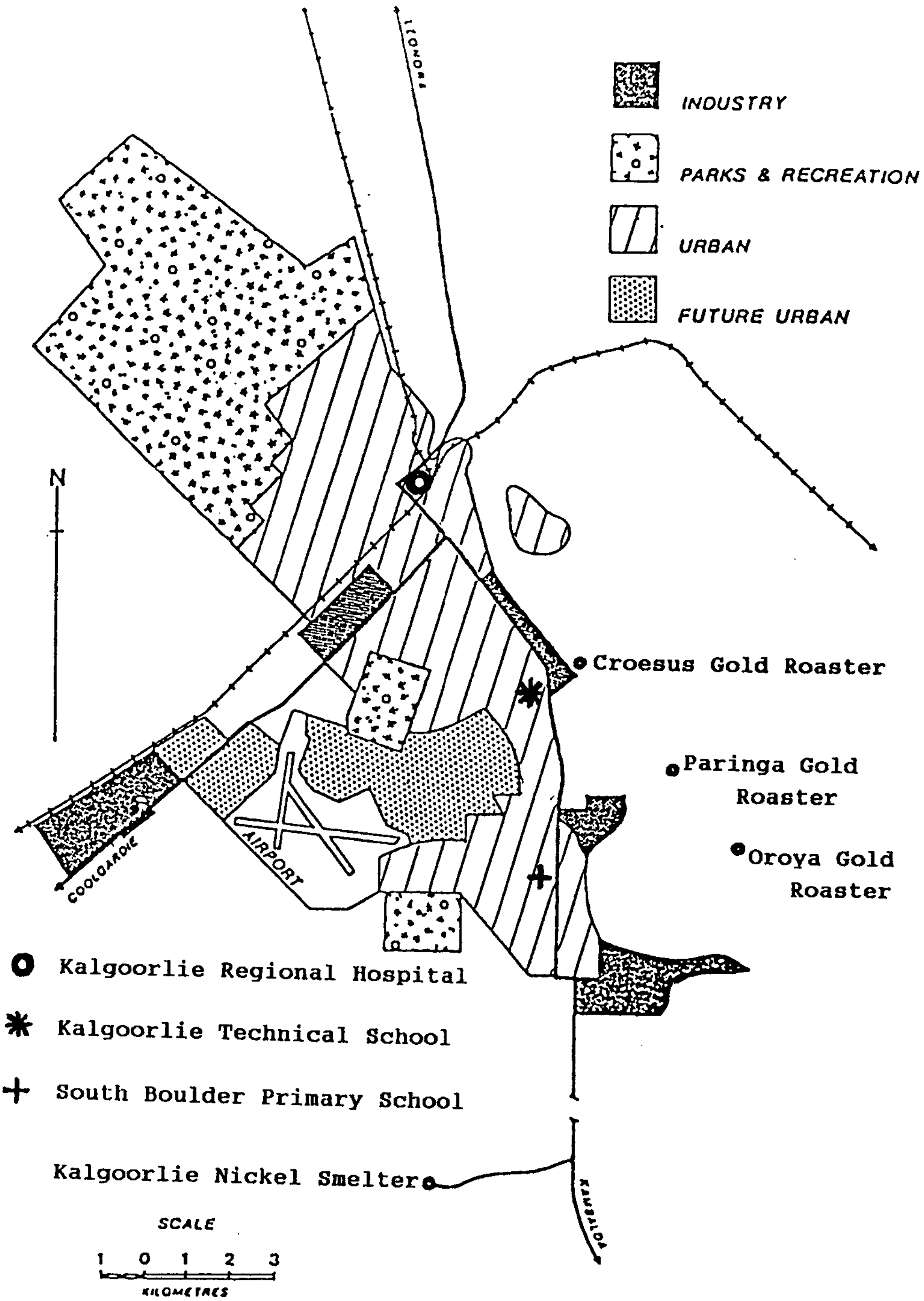

Figure 3. Plan of Kalgoorlie showing the locations of the roasters and three of the air quality monitoring stations.

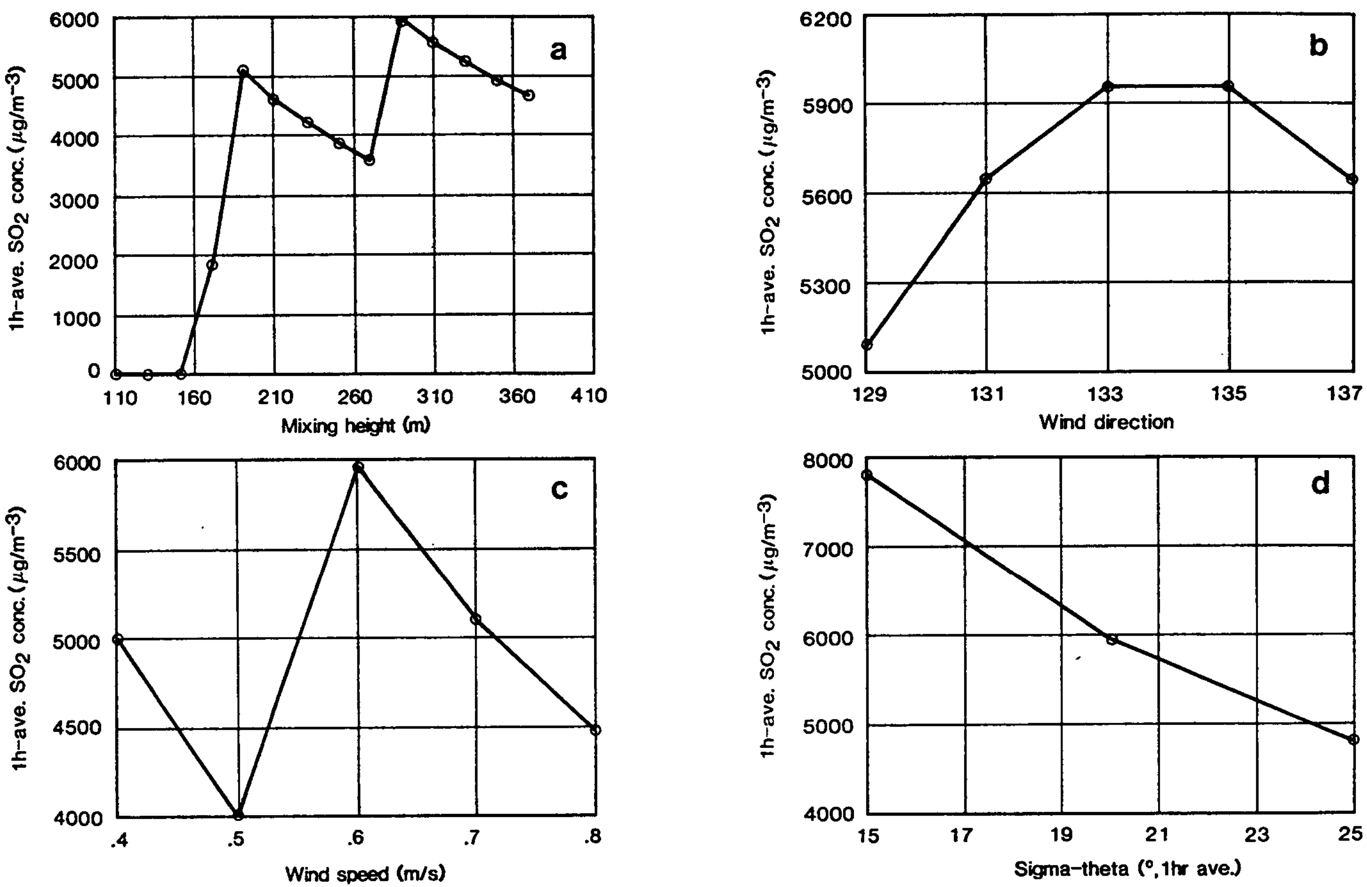

Figure 4. Sensitivity of predicted 1-hour average SO_2 levels at Kalgoorlie Regional Hospital to variations in :

a) mixing height

b) wind direction

c) wind speed

d) lateral mixing strength(σ_θ)

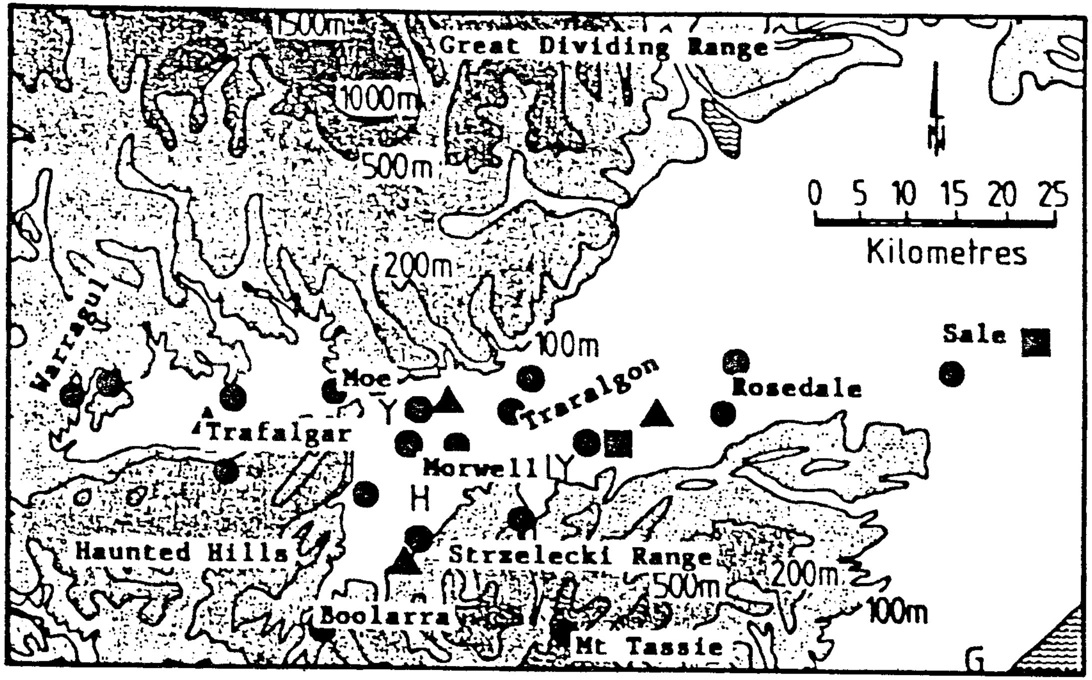

Figure 5. The Latrobe Valley, showing monitoring sites(●), major sources(H, Y, LY) and towns.

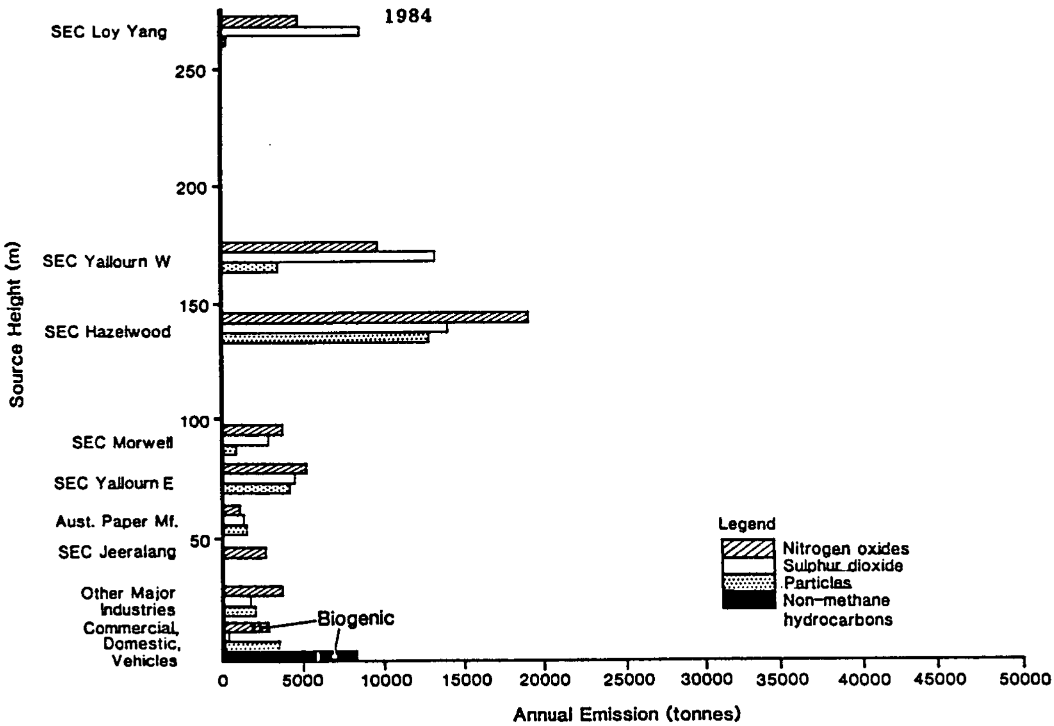

Figure 6. 1984 Emissions for the latrobe valley vs chimney height.

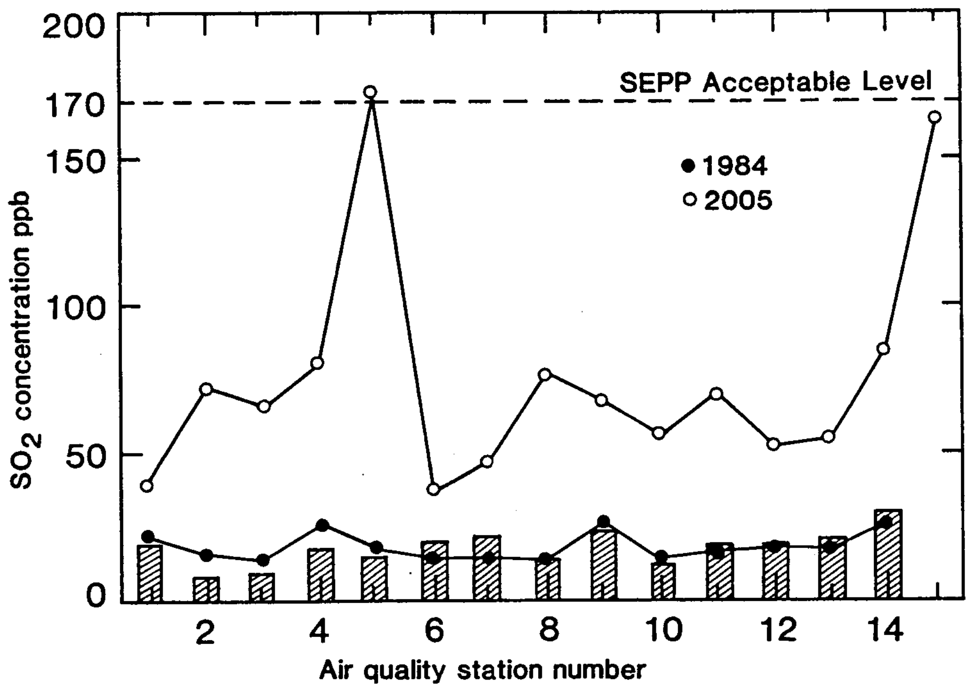

Figure 7. Validation of ISC for the Latrobe Valley for 1984 and predictions for 2005. Bars are as observed for 1984.