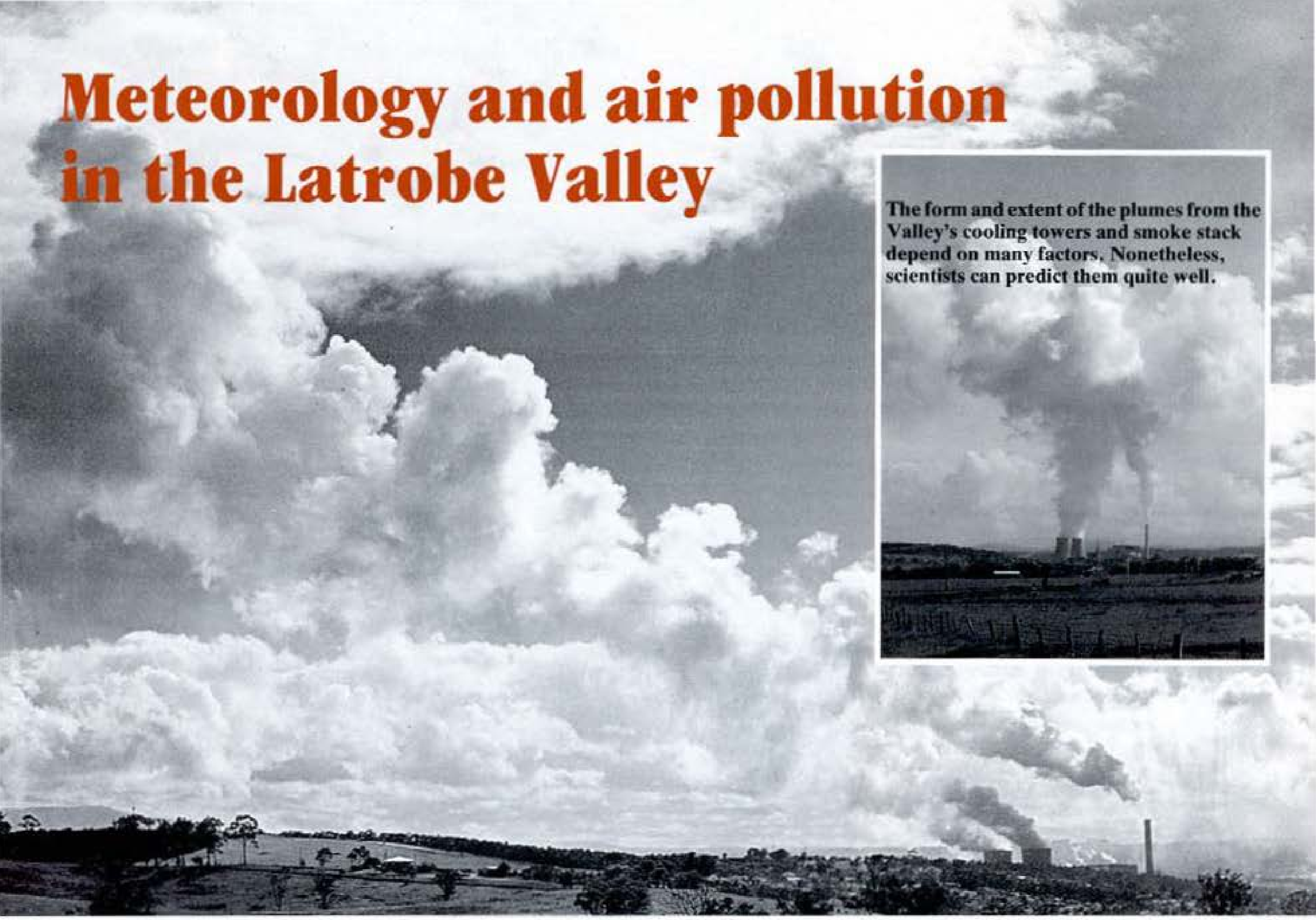
Meteorology and air pollution in the Latrobe Valley



The form and extent of the plumes from the Valley's cooling towers and smoke stack depend on many factors. Nonetheless, scientists can predict them quite well.

Victoria's Latrobe Valley presents a picture of contrast: colossal power stations amid lush green dairying country.

Brown coal is the reason for the rapid industrialization of the Latrobe Valley, which lies about 150 km east of Melbourne. Some 80% of Victoria's electricity is generated there, and other heavy industry includes the manufacture of paper, cement, and brown coal char. A coal-to-oil pilot plant is also under construction.

The Valley runs east–west and is bounded by the Great Dividing Range to the north (rising to more than 1500 m above sea level) and the Strzelecki Range (up to 760 m) to the south. It stretches about 80 km — from Warragul at the western end to Rosedale at the eastern end, with the sea some 40 km further east. A population of about 70 000 is spread between the several towns along the Valley.

The Valley's electricity-generating capacity, presently about 4000 MW, will rise to 6000 MW by the late 1980s with the completion of the Loy Yang A power station (the first 500-MW unit has recently been commissioned).

The State Electricity Commission of Victoria (S.E.C.) has identified possible sites for up to 21 new power stations, each of 2000 MW. Under the fastest growth scenario to the year 2030, a maximum of 16 of these would be in use at the same time. Clearly, continued development of the huge brown coal resource could not be contemplated without an assurance that the Valley's air could cope with the resulting emissions.

Victoria's State Environment Protection Policy (SEPP) has designated the Latrobe Valley as an 'air quality control region', and so controls on pollutant emissions from any new source must take into consideration existing air pollution levels and the effect of present and future neighbouring sources. In other words, controls will be more stringent in such a region than outside it in order to meet the State-wide air-quality goals, which are defined in terms of various pollutant concentrations that must not be exceeded with more than a certain frequency (see the table). 'Acceptable' pollution levels cannot be exceeded on more than 3 days per year (1 day for the 1-hour average of ozone pollution), while 'detrimental' levels are never to be exceeded.

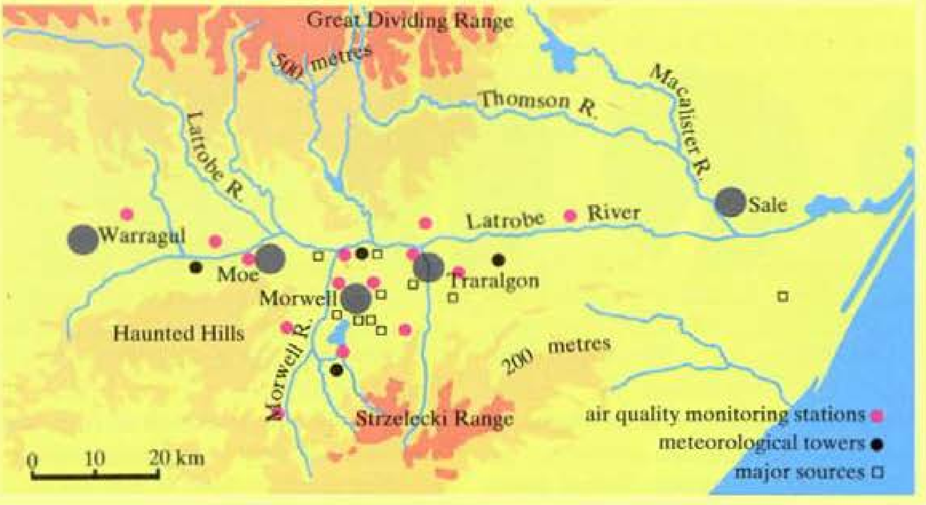
The Latrobe Valley Airshed Study was established in 1977 to monitor air quality in the Valley and to assess the region's capability to accept increased emissions in the future. Four organizations — the S.E.C.,

The air quality in the Valley is in most respects satisfactory. However, visibility is frequently below 20 km, and the 8-hour 'acceptable' level for ozone is sometimes exceeded.

Air quality of the Latrobe Valley

pollutant	averaging time (hours)	maximum concentration (p.p.b.)	'acceptable' level (p.p.b.)	'detrimental' level (p.p.b.)
sulfur dioxide	1	54	170	340
nitrogen dioxide	1	100	150	250
ozone	1	100	120	150
	8	77	50	80
carbon monoxide	1	12 000	30 000	60 000
		minimum local visual distance (km)	'acceptable' local visual distance (km)	
particulates	1	4	20	

The Latrobe Valley and its monitoring network



The monitoring stations and meteorological towers are connected to a central computer in Morwell.

Setting up a time-lapse camera to record the behaviour of plumes from Hazelwood power station.

the Environment Protection Authority of Victoria (E.P.A.), CSIRO, and the Latrobe Valley Water and Sewerage Board (LVWSB) — are formally represented in the organization of the Airshed Study. Other institutions, such as the Chisholm Institute of Technology and the Gippsland Institute of Advanced Education, also make contributions. Most of the costs are met by the S.E.C., since the findings have a large bearing on the Commission's future developments.

The major goals of the Study are to:

- monitor and describe the present quality of the air in the Latrobe Valley
- monitor the effect of meteorological conditions on the dispersal of emissions to the air
- list existing emissions from industry, motor vehicles and private homes and those expected to occur in the future
- mathematically model the behaviour of emissions in the atmosphere by programming a computer to use data from the Study to evaluate effects on air quality
- examine its measurements of the quality of the air and consider the likely future situation
- examine possible needs for emission control in the future and how this might be done

Most of the Valley's pollution is emitted through tall stacks.

Over the past 5 years the S.E.C. has spent close to $3 million on establishing an extensive and sophisticated network for monitoring air quality and meteorological conditions. This comprises 18 stations distributed throughout the Valley — from Darnum in the west to Rosedale in the east — all connected to a central computer at Morwell. Three monitoring stations in the main population centres are operated by the E.P.A. All stations are automatic, and are interrogated each minute by the central computer. Data are recorded, and hourly, daily, and monthly averages are calculated.

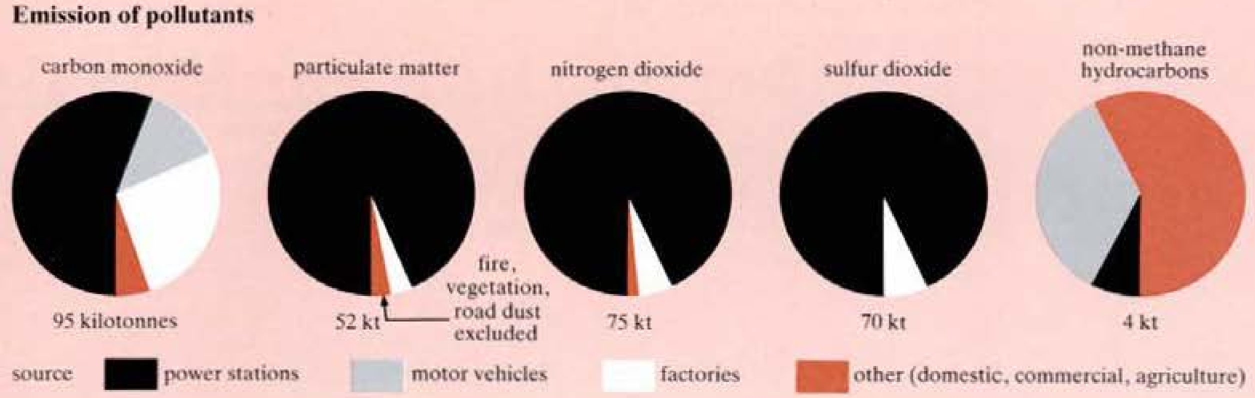
Air pollutant concentrations and meteorological conditions are recorded at 14 sites and, at the other four, detailed meteorological measurements are made on 110-m towers. A radiosonde station and a Doppler acoustic sounder gather data on meteorological conditions higher up.

The network has shown that air quality in the Latrobe Valley is in most respects satisfactory. The maximum values (averaged over an hour) for the concentrations of nitrogen dioxide, sulfur dioxide, and ozone easily meet the SEPP acceptable 1-hour levels. However, the 8-hour acceptable level for ozone is sometimes exceeded, and 'local visual distance' frequently falls below the acceptable minimum of 20 km due to airborne particles.

On average, values of local visual distance less than 20 km occur on about 10 days a year at rural sites and about 20–30 in the towns. This compares with about 40–50 days a year for Melbourne. (The measuring

Buoyant plumes rise through a fog layer, carrying pollution away from the Valley. The plumes belong to the Yallourn W power station.

Aircraft have been used to monitor the Valley's air quality higher up.



This inventory, drawn up by the Environment Protection Authority, and based on estimates from the Latrobe Valley Water and Sewerage Board, shows the major sources of emissions to the Latrobe Valley atmosphere and the amounts emitted in 1980/81. Because of the power stations' tall stacks, they contribute much less to ground-level readings than to total emissions.

equipment heats the air sample before making a reading, so these figures don't include the effects of mists or fogs, which are frequent in the Valley.) As with many air pollution measurements, these numbers can vary by factors of two or three from year to year, and site to site.

Various sources contribute to the impaired visibility. As well as industry, these include fires, and dusty roads and paddocks. Particles can also form in the air from the chemical reaction of emitted gases.

The proportion of total particulate emissions that is contributed by power stations is difficult to gauge, but the EPA has estimated that, after excluding contributions from fire, vegetation, and road dust, 90% comes from power stations. The contribution that power stations make to visibility reduction is even more difficult to estimate.

Power stations account for 93%, 92%, and 54% of the total output of sulfur dioxide, nitrogen oxides, and carbon monoxide, respectively, and these are from stacks ranging from 32 m (Jeeralang) to 260 m (Loy Yang) in height.

The Health Commission of Victoria is in the preliminary stages of a long-term epidemiological study of the Valley's population. The aim is to discover whether any health effects are associated with the pollution produced by the coal-burning power stations.

Here to there

The EPA has drawn up an inventory of the strength and number of the sources of each pollutant, and data on the Valley's air quality are steadily building up. Next comes the difficult part — finding the relation between a given source and its contribution to the general pollution level.

Pollutants are commonly emitted at concentrations 1000 times greater than the levels set for desirable ambient air quality. The processes of diffusion and dilution in the atmosphere are therefore of fundamental importance.

Understanding these processes calls for a study of chimney plume behaviour and turbulent mixing. Factors involved include wind speed, chimney height, inversion layer height, local topography, and the current weather conditions.

Researchers are attempting to build mathematical models that incorporate the important meteorological factors and allow the pollutant concentrations to be calculated. An accurate mathematical model would be able to show, for example, how many power stations with specified pollutant outputs and chimney heights can be built at a particular site without producing unacceptable pollution levels.

Good progress has been achieved in defining the average and extremes in air quality, and linking them to particular meteorological circumstances. Some of these findings, and some of the fundamental research problems being tackled, are outlined below.

Inversion layers effects

Compared with Melbourne, the Latrobe Valley has more days with low 'ventilation rates' (days when the number of air changes per hour is small). Ventilation rates are the product of wind speed and height of the 'mixing layer', the layer of the atmosphere immediately above the ground in which the air mixes freely. Low ventilation rates usually occur when a low-altitude temperature inversion has produced a shallow mixing layer. Such days are more likely to succeed one another in the Latrobe Valley than in Melbourne — allowing pollution levels to build up.

However, the situation is not as bad as it sounds. Most of the Valley's pollution is emitted through tall stacks, so when the mixing layer is shallow, pollution escapes above it. When the mixing layer is deep, emissions are caught up in it, but there is a lot of air to dilute them. In Melbourne, by way of contrast, most of the pollutants are emitted near ground level, so the days of worst pollution occur when the mixing layer is shallow.

'Fumigation' is the most common cause of the higher pollutant concentrations.

Recognizing the importance of the inversion layer, which often limits the depth of the mixing layer, a number of scientists in the Airshed Study team have devoted much time to it. They include: Mr Richard Hoy, Mr Roger Tapp, and Mr David Jones, of the S.E.C.'s Herman Research Laboratory; Dr Peter Manins, Dr Kevin Spillane, and Dr Bill Physick, of the CSIRO Division of Atmospheric Research; Ms Sabriye Ahmet of the E.P.A.; and Mr Bill Moriarty of the Bureau of Meteorology.

On the observational side, Mr Tapp and Mr Hoy have made studies of the height and strength of inversion layers using daily radiosonde data for 2 years. Mr Jones used acoustic sounding, which detects echoes from air parcels of differing temperature, to provide further useful data on inversion heights.

Dr Manins has made theoretical studies of the way in which a smoke plume, driven by buoyancy forces, breaks through an inversion layer. He has analysed the process mathematically, and come up with a formula that predicts what fraction of the emissions will become trapped in the inversion layer. Modelling of the process in a water tank has confirmed the correctness of the theory.

Mr Moriarty has made calculations that suggest that if all nitrogen oxide emissions came from stacks as tall as Loy Yang's (260 m), then such emissions should penetrate the inversion layer on most days: only on 11% of days would concentrations build up significantly in the Valley. While a 'tall stacks' policy has a large effect on local pollution levels, it does less to alleviate effects that the emissions may have on air quality far from the source. Because of this, it is still necessary to control the quantities of pollutants released.

Trapping of pollutants in the inversion layer has very significant consequences. For when the inversion layer begins to break up — as it tends to do with the morning sun — this store of pollutants can be rapidly mixed back down to earth as vigorous convection cells start operating.

Mr Hoy has studied the times at which pollution levels are highest, and concluded that this process, called 'fumigation', is the most common cause of the higher pollutant concentrations. Elevated concentrations of sulfur dioxide (almost exclusively of power station origin) were found most frequently between 10 a.m. and noon — just when inversion layers are usually breaking up. Other causes, such as 'looping' and 'coning' of a plume back to the ground, were relatively rare causes of higher concentrations.

The data also showed that the highest concentrations of nitrogen oxides are due to local low-level sources in townships.

What's going on?

The Study has considered other meteorological mechanisms that could cause high pollutant concentrations. These include sea breezes; drainage flows caused by layers of cold night air streaming down hillsides; and separated reverse circulations (a result of wind blowing across the enclosing mountains and setting up an eddy in the valley below).

SEA BREEZES

The sea breeze, an important event in summer in the Latrobe Valley, has been studied by Mr Tapp and Mr Hoy, and more recently by Dr Physick. Results from studies of wind records, and experiments involving the tracking of the sea breeze along the floor of the Valley by an instrumented vehicle, have shown that it can on occasion penetrate 110 km or more inland — from the coast to as far as Warragul. The experiments have also shown that the sea breeze sometimes progresses in a surging manner — and that there are actually two different sea breezes. One comes from the east coast while the other, less frequent, comes from the south coast up the Morwell River Valley.

The sea breezes can act as a flushing mechanism, bringing an influx of clean sea air. However, while they usually improve the air quality in most regions, on occasion they may push emissions to upper parts of the Valley, increasing pollution levels there.

On some days both sea breezes operate, usually meeting somewhere between Hazelwood and Traralgon. Under these conditions, higher pollutant concentrations may be experienced as emissions carried by the southerly breeze are brought back by the one from the east.

DRAINAGE OF COLD AIR

Early in the Study, the question was raised whether chimney plume emissions could strike the upper walls of the Valley at night and then get taken down to the valley floor by sinking cold air.

Since little was known about such air movement, known as katabatic wind, Dr Manins and a colleague at the CSIRO Division of Atmospheric Research, Dr Brian Sawford, carried out experiments to measure the scale of this effect, and also modelled it mathematically.

Their work showed that only a shallow layer of air, generally less than 80 m thick, behaved this way, and that entrainment of pollutants in it would be rare. On the other hand, low-level emissions from towns can be trapped below or in the cold air layers that form on the valley floor.

BLOCKING

Another night-time phenomenon (when the air is stable) has been proposed as a major cause of some high ground-level pollutant concentrations. This is 'blocking', and occurs when wind blows across the top of the valley and sets up an eddy beneath (as happens when one blows across the mouth of a jar).

The resulting circulation can recycle emissions, and Dr Manins and Dr Sawford have studied this behaviour in the field and with water-tank and mathematical models. This is an area where further understanding is being pursued.

MULTIPLE SOURCES

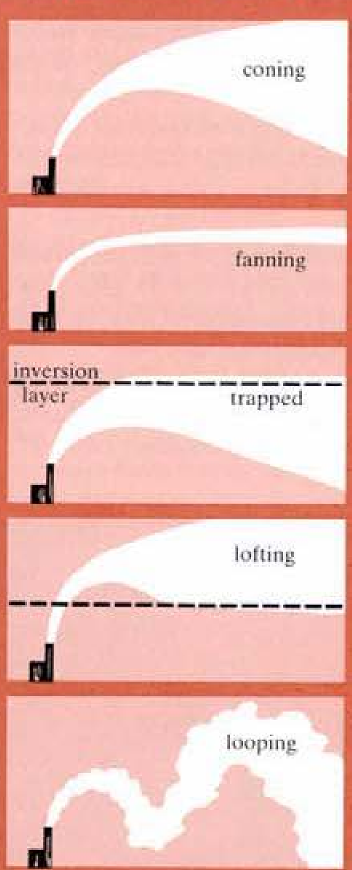
Power stations are effectively point sources of pollutants, and each contributes to the ground-level concentration at any point according to wind speed and direction, and other meteorological factors such as turbulence. A monitoring station measures fluctuating quantities, which can be expressed as a mean value subject to a certain statistical variance.

Air quality regulations are concerned with the maximum values, and often specify the frequency with which a given concentration level may be exceeded.

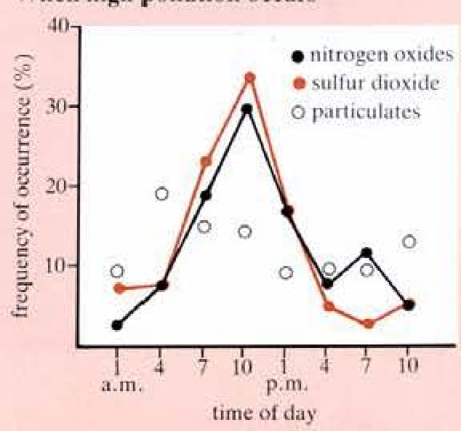
What happens when two point sources interact? Dr Sawford is conducting theoretical and experimental studies to find out how the combined effect compares with that of each source on its own.

Present practice is conservative: it assumes that mean pollution concentrations will be the sum of the levels expected from the two sources individually, and so will maximum levels. In fact, this is true only for the worst possible situation, which happens rarely. An accurate analysis of the situation must capture the generally co-ordinated *pas de deux* of a pair of chimney plumes. The peak-to-average variation is less with two

Different kinds of plume behaviour



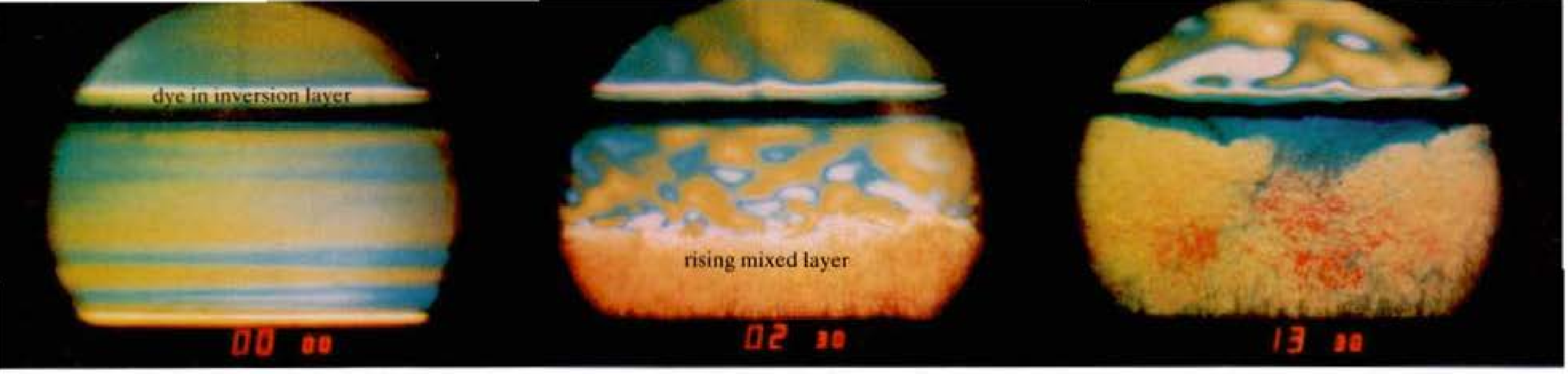
When high pollution occurs



measurements at Trafalgar North, May 1980–Aug. 1982

***Right*: The highest 2% of pollution readings for nitrogen oxides and sulfur dioxide (power station sources) occur at mid morning, when the inversion layer is breaking up. Particulate readings do not follow the same pattern.**

***Left*: Plumes can behave very differently, depending on the temperature profile of the atmosphere.**



How turbulent mixing can bring down to earth pollutants initially trapped aloft in an inversion layer. This is an important phenomenon in the Valley, and is seen here in a laboratory model.

sources than with one, and if this could be quantified it would permit the licensing of groups of major sources that would otherwise appear unacceptable.

Dr Sawford, in collaboration with the S.E.C., has studied how two plumes overlap: he has released phosphorus smoke and sulfur hexafluoride from two sources and detected each component some distance downwind. Present work is with experimental plumes at quite short range; later, he hopes to do similar studies with plumes from power stations.

PLUME VISIBILITY

Clouds resulting from condensation in plumes from power station chimneys and cooling towers can have a large visual impact, even though water can hardly be called a pollutant. Predicting the size and frequency of occurrence of such clouds is of some importance, and Dr Spillane and his colleague at the CSIRO Division of Atmospheric Research, Mr Clive Elsum, have been involved in this undertaking.

The raw brown coal of the Latrobe Valley has a water content of 60%–70%, and water formation during combustion adds to the moisture of the emerging gases. The Latrobe Valley has generally high humidity and experiences frequent fogs (about 1 day in 3 in winter), so visible plumes from the stacks are large and frequent. Cooling towers also produce plumes — the emerging air has a humidity close to 100%. The two types of plume behave differently, and often one is visible but not the other.

Dr Spillane and Mr Elsum have developed a mathematical model of plume rise and condensation, which they have used to predict the visibility of the plumes from the new Loy Yang power station. The model had already been tested, with good results, on cooling tower plumes from the Yallourn W power station and on plumes from the stack at Newport D in Melbourne.

The model predicts that on 1 day in 2 a cloud of condensation from the stacks should be visible, and on 11 days a year spectacular plumes should extend to more than 800 m (above the height of the surrounding ranges). On 1 day in 5 a cloudy stack plume would be visible at long range.

As to the cooling tower plumes, on 1 day in 3 high humidity should cause persistent cloud to form. However, four-fifths of these would merge into overcast low cloud and wouldn't be clearly visible. Only on 1 day in 33 would the plumes become visible against a clear sky or broken cloud.

Fogs in the Yallourn–Morwell area are more intense and persist later than elsewhere in the Valley. This appears to be due to low-level emissions of water vapour from the power stations and smoke from nearby industry. The Loy Yang cooling tower outlets are higher than the top of most fogs, and so Loy Yang should have no discernible effect on fog occurrence — the plumes rise above the fog.

How many Loy Yangs?

A primary concern of the Latrobe Valley Airshed Study is to assess the airshed's capacity for future emissions. This hinges largely on the ability of large plumes to escape the mixing layer.

An early report by the Bureau of Meteorology, based on very limited monitoring and considering only nitrogen oxides as a pollutant, suggested that the Valley could accommodate at least 15 operating power stations the size of Loy Yang A. However, the pollutants presently of most concern, ozone and particulates, have not been addressed in any reports that explore the airshed's capacity.

Now that extensive high-quality data are being gathered and more sophisticated models constructed, scientists are making good progress in understanding the subtleties of the Valley's meteorology and they should soon be able to make more definite predictions.

A major experiment in June 1984 involved the CSIRO Division of Fossil Fuels in tracking the stack plumes by instrumented aircraft. The experiment was the first of four planned, and they should shed further light on inversion trapping, plume dispersion, and air circulation under various conditions.

The results will be important to knowledge of the Latrobe Valley's environment, and of that around many other Australian power stations.

Andrew Bell

More about the topic

Concomitant research from the Latrobe Valley Airshed Study. P.C. Manins. *Australian Meteorological Magazine*, 1984, **32**, 95–9.

The Latrobe Valley Airshed Study: its significance as a tool for future planning. J.A. Hart. *Clean Air*, 1981, **15**, 49–55.

'The Air Dispersion Capability of the Latrobe Valley Airshed: a Brief Overview.' (Bureau of Meteorology: Melbourne 1981.)

Nocturnal air circulation in the Latrobe Valley. P.C. Manins. *Clean Air*, 1983, **17**, 29–32.

Atmospheric boundary-layer measurements of concentration statistics from isolated and multiple sources. B.L. Sawford, C.C. Frost, and T.C. Allan. *Boundary-Layer Meteorology*, 1985, **30** (in press).

An initial assessment of pollutant dispersion by sea breezes in the Latrobe Valley. W.L. Physick. *Clean Air*, 1983, **17**, 24–8.

Aspects of high hourly air pollutant events in the Latrobe Valley. R.D. Hoy. *Papers, Eighth International Clean Air Conference, Melbourne, May 1984.*

Prediction of cloud effects in chimney plumes. K.T. Spillane and C.C. Elsum. *Atmospheric Environment*, 1983, **17**, 983–90.

Red and green dyes issue from a scale model of Victoria as it is towed through a water tank from left to right to simulate the effect of north-easterly winds. Notice that the red dye from the Latrobe Valley, caught in a wake from the Great Dividing Range, first travels east before proceeding west.