ENVIRONMENT PROTECTION AUTHORITY

SmokeWatch Adelaide Hills Pilot Study Part 1 2006

EPA
South Australia

SmokeWatch
Adelaide Hills Pilot Study Part 1
2006

SmokeWatch Adelaide Hills Pilot Study Part 1, 2006

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GLOSSARY

Fine particles	Particles measured via a nephelometer; a close approximation to $PM_{2.5}$ particles
NEPM	National Environment Protection Measure, and is a national legislated policy that sets limits for the highest permissible pollution levels for a limited range of pollutants.
NO_X	Total nitrogen oxides
NO_2	Nitrogen dioxide
NO	Nitric oxide
CO	Carbon monoxide
PM_{10}	Particulate matter with an equivalent aerodynamic diameter of 10 μm or less
$PM_{2.5}$	Particulate matter with an equivalent aerodynamic diameter of 2.5 μm or less
ppm	Parts per million (by volume)

SUMMARY

The South Australian Environment Protection Authority (EPA) undertook air monitoring from early June to the end of September 2006 for the SmokeWatch education program at Woodside.

This study provided an excellent opportunity to identify different sources of pollution and to assess the impact of wood smoke in an isolated airshed.

The EPA was able to clearly identify an impact from wood smoke in an area with a small population.

Monitoring highlighted that the air quality was generally good in Woodside during the study, with the impact of wood heaters only being detected during cold and still nights. These wood smoke events were transient in nature and quickly dispersed as the morning breeze developed.

Through extrapolation of the findings, it is possible to estimate a population density in Woodside that would produce a smoke problem.

INTRODUCTION

The 2006 SmokeWatch program incorporated a behaviour change component and involved councils and local schools helping to deliver the program. By having the community participate in the program resulted in meeting a number of objectives including:

- raising awareness of the polluting effects of wood heating
- building an understanding of good wood heating practices to minimise pollution
- raising awareness of the role that EPA and the state government have in monitoring pollution in South Australia.

The program involved promoting concepts for use of slow combustion heaters, such as the type of wood to burn, and how to determine whether the heater is working effectively.

SmokeWatch was implemented in partnership with the Adelaide Hills Council from June–October 2006. The Adelaide Hills Council involvement was crucial to the implementation of the SmokeWatch program as the council already has effective mechanisms in place for communicating with residents in their area.

A short-term pilot monitoring study was undertaken in the township of Woodside to assess background air quality. Having this information would provide a better understanding of the effects and impacts of wood smoke in the Adelaide Hills.

A survey was conducted to establish the number of people using wood heaters as a primary or secondary heating method. The survey results also detailed how often people use their wood heaters, where they obtain their wood, and whether they maintain their heaters.

The main components of wood smoke pollution are (in varying amounts) carbon monoxide, fine particles, volatile organic compounds and nitrogen oxides (NSW EPA 2007). The particles are a very complex mixture of solids and liquids, including carbon and a whole range of chemicals formed by incomplete combustion of wood, many of which are toxic or irritating.

The EPA used an air monitoring caravan for measuring wood smoke; the caravan houses several instruments that measure particles, gases and meteorological events. The EPA measured the main pollutants from a combustion process; however, while there are many different types of hydrocarbons released from combustion, only a selection of the more volatile chemicals were monitored by EPA.

The pollutant, wood smoke, is classified as being a diffuse source. This means that it typically originates from many individual minor point sources dispersed across an area. Emissions from one wood heater can be radically different from another, and depend upon such factors as fuel burnt, design of the heater and whether it is in startup or ongoing mode.

WHERE DID AIR MONITORING OCCUR?

The site selected, the Woodside Primary School, is in the Adelaide Hills Council District of Woodside. This location was selected for a first investigation of the impacts of wood smoke in the Adelaide Hills. The site offered a number of unique conditions for the study that served to limit the number of pollution sources. For example, the township's location in the Adelaide Hills meant that it was likely to experience only low levels of pollution transported from other sources/regions. Woodside was also considered to be large enough to detect wood smoke events from local sources, a fact confirmed with discussions with school staff.

The school offered several advantages for a monitoring site in terms of being centralised in the township. As it was in the school grounds, results obtained were from an area containing a 'at risk' population[1].

Figure 1 shows the contours of the land surrounding the site. Appendix 1 shows where Woodside is located in relation to Adelaide CBD.

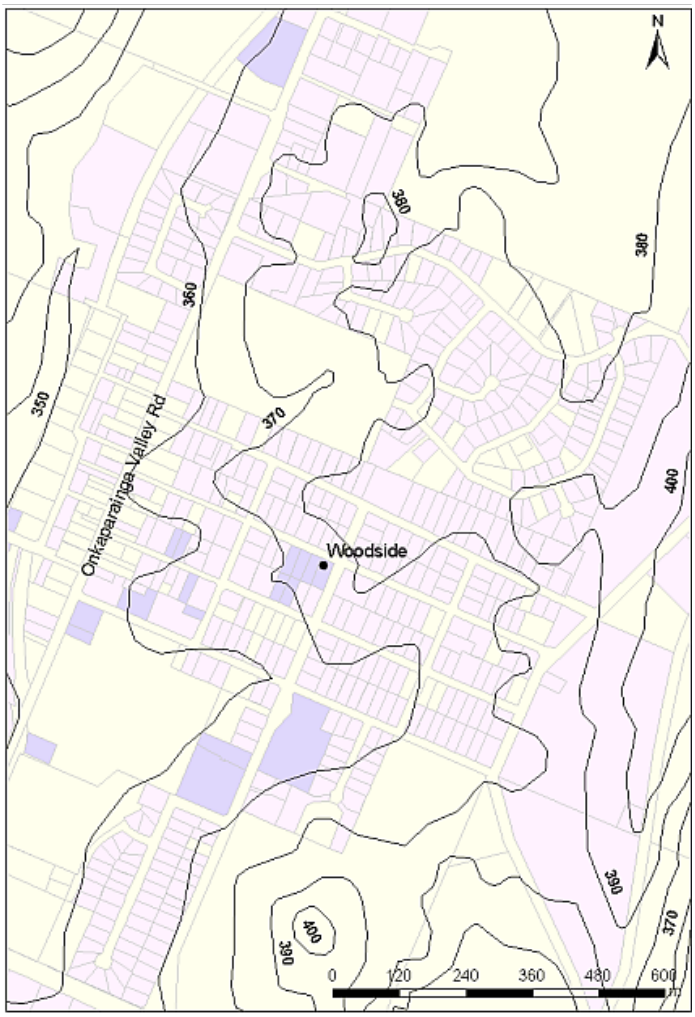

Figure 1 Map showing the Woodside monitoring site and contours

[1] At-risk populations include the young, elderly and those with medical conditions.

WHAT WAS MEASURED?

Smoke is a complex mixture of chemicals (Todd 2003), including inorganic and organic compounds. The particles in wood smoke have diameters of 0.6 to 1 μm (Environment Australia 2002). To detect wood smoke the EPA needed to measure both the gaseous and particle pollution released when wood is burned. The gaseous pollutant that was measured and is of main interest to this study is carbon monoxide. This gas is released during incomplete combustion of carbon fuels such as wood. Other gaseous pollutants measured include nitrogen oxides, formaldehyde, benzene and sulfur dioxide, all of which can be released in varying amounts from burning fuels, including wood.

Particles smaller than 10 μm in diameter (PM_{10}) were measured using two instruments. One instrument (TEOM) effectively weighs how much PM_{10} is in the air. The second instrument (nephelometer) measures the light scattered by fine particles; the amount of particles in the atmosphere affects how far a person can see (visual distance). This nephelometer can also provide an estimated mass of 'fine particles' or particles smaller than 2.5 μm ($PM_{2.5}$). For the purposes of this report particles measured by the nephelometer will be referred to as 'fine particles'. The use of two methods for measuring particles was intended to assist in determining how small the particles present in air actually are. If most of the particles present are in the fine particle range, then this suggests pollution dominated by wood smoke.

The ultimate concentration of pollutants released into the air is affected significantly by the weather. In particular, cold still conditions (known as inversions) act like a lid, trapping smoke and allowing it to build up. The EPA also measured wind speed and direction, air temperature and pressure. These meteorological measurements assisted the EPA to determine pollution sources and the various conditions causing pollution to be diluted, dispersed or trapped.

During the study, smoke-based pollution events always coincided with low temperature and low wind speed. The topography of the study area, along with the other factors, had the effect of trapping pollutants.

How much pollution from wood smoke is released in Adelaide?

The amount of pollution released in the greater Adelaide airshed has been estimated via an emissions inventory program named the National Pollutant Inventory (NPI). NPI estimates emissions from industrial facilities and diffuse sources, such as solid-fuel burning (domestic). This classification includes wood heaters, cookers and also outdoor burning activities carried out in residential properties not associated with industry.

While the Adelaide airshed does not yet include Woodside or much of the Adelaide Hills, the information from the NPI highlights how many small sources can collectively cause a larger impact.

Of interest to the study was information collected by the NPI regarding carbon monoxide, particles as PM_{10}, oxides of nitrogen (NO_X) and volatile organic compounds. Solid-fuel burning (domestic) accounts for an estimated 9.3% of Adelaide's air emissions (NPI 2007), highlighting that, while one heater may not cause a great deal of pollution, many heaters collectively can contribute substantially to air pollution levels.

In particular, NPI estimates in Adelaide highlight that carbon monoxide emissions from solid-fuel burning (domestic) is second only to motor vehicles, and for particles as $PM_{10,}$ solid-fuel burning (domestic) is the third largest source. The compounds of interest in this study are outlined in the table below, including the amounts released to the Adelaide airshed.

Table 1 NPI emission estimates for solid-fuel burning (domestic) in the greater Adelaide airshed (NPI 2007)

Pollutant	Mass released tonnes/year
Carbon monoxide	28,000
Particulate matter PM_{10}	1,600
Volatile organic compounds	8,200
Formaldehyde	300

What did the telephone survey tell us?

The telephone survey was conducted in July 2006 to determine the number of people using wood heaters and the way they used them. The telephone survey was conducted by a research organisation (McGregor Tan Research) on behalf of the EPA, and focused only on the Adelaide Hills Council area. The survey consisted of approximately 25% Woodside residents and 75% from other regions within the Adelaide Hills Council area.

The survey found that half of the respondents had been negatively impacted by wood smoke, naming odour as the primary source of concern.

The survey also showed that:

- 72% of people surveyed used wood heaters
- 63% used them as their primary form of heating.

Of those using wood heaters:

- 49% of people sourced wood from their own property
- 43% sourced wood from a wood yard
- On average it was found that the respondents used 3.1 tonnes of wood per year, of which 87% was seasoned wood
- 55% of respondents used their wood heaters in the evenings
- 21% used them 24 hours a day
- 96% of people used them in winter
- 48% used them in autumn
- 35% of people used them in spring
- 39% of respondents kept their wood heater air vents open 20 minutes after lighting a fire
- 43% partially closed the air vent less than 20 minutes after lighting a fire
- 48% of wood heater users cleaned their flues once per year
- 50% of respondents checked their chimneys 20 minutes after lighting to check for wood smoke
- 72% of respondents agreed they ensured their heater did not produce unnecessary smoke.

The survey indicated that the main areas where improvement might lie were

- keeping air vents open longer
- checking for wood smoke after lighting a wood heater
- cleaning flues.

What was the air quality at Woodside like?

The air quality at Woodside during the study was found to be good to very good compared with current standards. The study did not detect any events above National (NEPM) Standards or Goals for the relevant parameters, as shown in Table 2.

The highest readings reached approximately 60% of the relevant standard for PM_{10}, benzene and formaldehyde. It should be noted that the relevant standard for benzene is very low (0.003 ppm) and the levels measured were at the lower detection limit for the instrument.

The particle levels were found to be high for short periods during the night. These events were at times when it is expected that the majority of the population would typically be indoors (9.30 pm to 5 am). As the morning breeze developed, the pollution was dispersed and air of very good quality dominated. The highest PM_{10} day recorded was the occasion when there were predominantly smoke-related particles in the air. As such a large proportion of these particles are $PM_{2.5}$ there is a possibility of approaching the $PM_{2.5}$ NEPM standard of 25$\mu g/m^3$ as a daily average. The $PM_{2.5}$ values are an approximation and, if comparison with the NEPM were to be investigated, a standard measurement method would need to be utilised.

Table 2 Woodside monitoring results compared with the NEPM Standards (EPHC 2007)

Pollutant	Highest NEPM average measured	NEPM (National Standards/Goals)	
		Standard / investigation limit	Events>standard
PM_{10}	29.6 $\mu g/m^3$	50 $\mu g/m^3$ (24-hour average not > 5 events/year)	0
CO	1.7 ppm	9 ppm (8-hour rolling average)	0
NO_2	0.023 ppm	0.12 ppm (1 hour average)	0
SO_2	0.007 ppm	0. 20 ppm (1 hour average)	0
Benzene *	0.002 ppm	0.003 ppm (annual average)	0
Formaldehyde	0.025 ppm	0.04 ppm (24-hour average)	0

***Note:** Benzene has an annual averaged Air Toxics NEPM Investigation Level. As there are insufficient data for an annual average, the mean value during the monitoring was used for comparison.

HOW DO WE KNOW WHAT CAUSED THE POLLUTION?

Time of events

As would be expected, the time that people light wood heaters is strongly dependent on the times they are home and the ambient (outside) temperature. Of those surveyed, 55% of people lit their wood heaters in the evening (for the evening), while 21% used them 24 hours a day.

Vehicles are expected to have reduced activity overnight and increased activity during the early-to-mid morning, continuing during the day, to peak again in the early evening. Using these assumptions, we can begin to develop a pattern of the emissions of pollution from heater use and other sources.

Wood heater use will be associated with an increase in the levels of particles and gaseous pollution. Figure 3 shows a typical day in August 2006 where particle levels tended to increase in the mid-evening (4–6 pm). This is assumed to be the time that people are returning home and also corresponds to the time that the ambient temperature generally begins to decrease. Particle pollution continues through to the early hours of the morning (2–3 am) before dropping back towards the background concentration. The maximum quantity of particles in the air is estimated to be up to 95$\mu g/m^3$ above the background concentration.

During the morning it is assumed that people would restart wood heaters and use their motor vehicles. This can be seen in Figure 2 where particles increased during the mornings of the 10 and 11 August. After mid-morning the temperature and wind speed typically increased, resulting in the pollutants being dispersed.

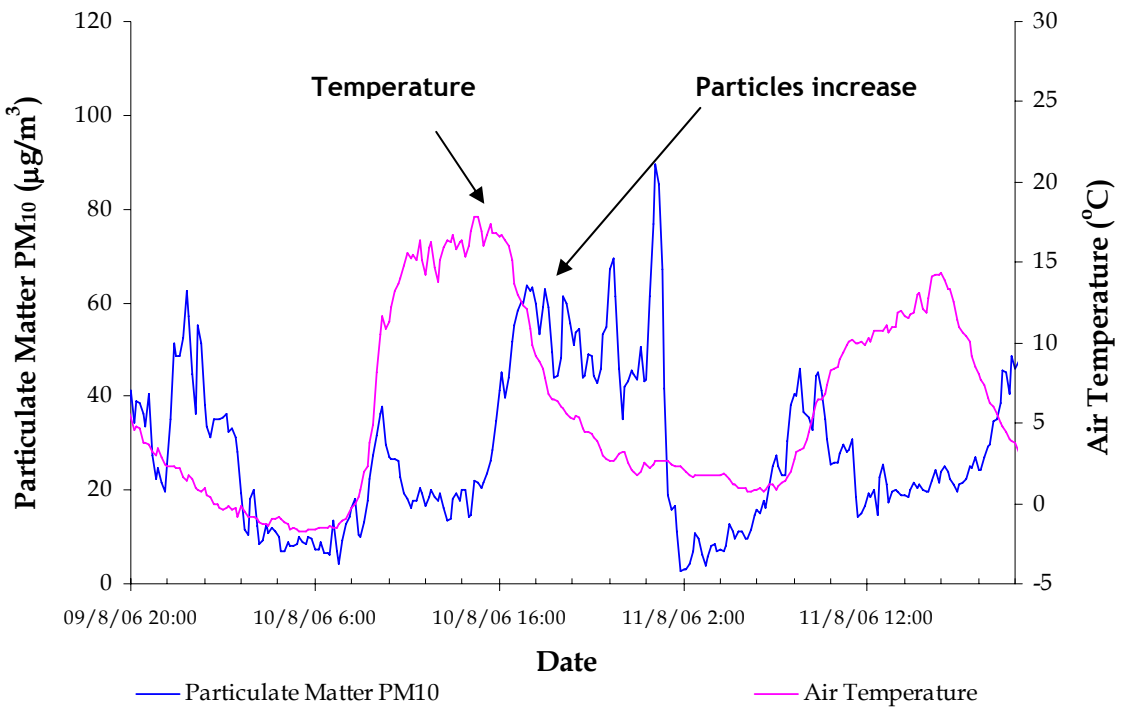

Figure 2 **PM_{10} concentrations with the corresponding ambient temperature, 9–11 August, Woodside**

Meteorological effects

Results from monitoring indicated that, during periods of low wind speed (less than one m/s or 3.6 km/hr) and low temperatures (Figure 2), fine particle pollution increased. During periods of higher wind speed (greater than one m/s), the larger particles in the air increased and the finer particles were displaced and or/diluted. Smoke is predominately made up of fine particles and gases that are more easily dispersed by gentle winds. A typical example of this is shown in Figure 3, which shows results of monitoring of fine particles using a nephelometer on a typical evening.

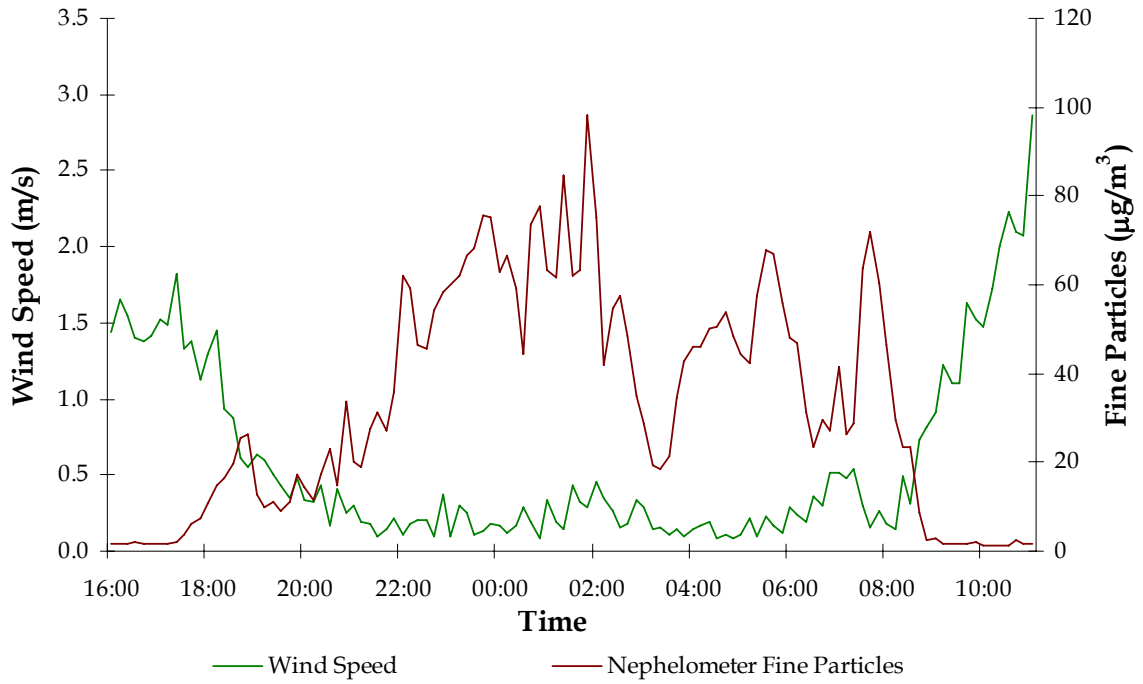

Figure 3 Particles (using nephelometer) and wind speed for a typical evening, September 2006

It is expected that major particle sources during the night would be wood heaters or open burning. Figure 3 shows that the particle levels can cycle, depending upon winds and smoke emissions. Overnight the level of fine particles typically increases gradually until approximately 2 am. The fine particle level reduces around this time, probably due to a decrease in the number of heaters operating and a slight increase in wind speed. When the wind speed decreases again, it results in an increase in particle pollution once more. This cycle, where particles increase and decrease, continues until the morning breeze develops enough speed to transport the pollution away.

Wind speed is most critical when discussing the prevalence of wood smoke in the study area. Wood smoke tends to pool in low-lying areas at low wind speeds. Once wind speeds increased beyond one m/s (or 3.6 km/hr), particle levels were reduced and smoke was transported away from the township.

This weather pattern was repeated for just over half (53%) of the days during the study. Because of Woodside's geographical location, there are few, if any air pollution sources nearby, meaning that most of the pollution measured was from local residential sources in Woodside.

Pollution patterns

There were many occasions where wood smoke was present at the monitoring site. This was determined by the ratio of the finer particles to the PM_{10} particles and levels of carbon monoxide (CO) and oxides of nitrogen (NO_x).

Combustion processes produce CO and NO_x in varying amounts. The relative amount measured gives an indication of the source of the combustion. For example, motor vehicles give a mix of these pollutants different from that of the combustion of wood in wood heaters.

NO_x is made up of two main components: nitric oxide (NO) and nitrogen dioxide (NO_2). If more NO is present than NO_2, then the source is likely to be combustion at a high temperature, such as within a motor vehicle. If there is more NO_2 than NO, then the source is likely to be lower-temperature combustion, suggesting wood heaters. Another source of NO_2 is old pollution or transported pollution plumes from a location with high NO emissions upwind of the site. So it can be seen that the relative amounts of NO and NO_2 can also assist in determining sources.

However, CO levels vary and depend on a number of factors. CO is produced during incomplete combustion of carbon-based fuels such as an air-dampened wood heater. Motor vehicles without catalytic converters or at cold start will also emit appreciable amounts of CO. It is expected that most emissions of CO from motor vehicles occur during daytime hours, whereas wood heaters are generally operating from evening to early morning. These different patterns in conjunction with data on other pollutants can assist in identifying when wood heaters are the predominant source of emissions into the local air.

Monitoring showed that when fine particle levels were high, the CO concentration was elevated and the NO_2 was higher than NO, suggesting wood heaters as the dominant source. When PM_{10} particle levels were high, there were lower NO_2 and CO levels, suggesting a different source.

The particle peaks shown in Figure 2 were observed during low overnight temperatures and low wind speeds. Under these conditions particles would originate from a localised source, which is also indicated in the data by the signature of the plume measuring a sharp peak.

As with gaseous pollution, PM_{10} and fine particle pollution will give an indication of the source. During the study many particle events were found to be predominantly comprised of fine particles (Figure 4). This is a strong indicator of wood smoke, which consists of fine particles rather than larger particles. Particles from other sources present in Woodside at these times include motor vehicles; however, the expected number of vehicles present would not contribute much to the particle pollution. As a consequence of the time the events occur and when the ambient temperature decreases, the peaks in Figure 4 can be attributed to wood smoke emitted from combustion heaters.

It can be claimed with a high degree of confidence therefore that the major particle source is wood smoke.

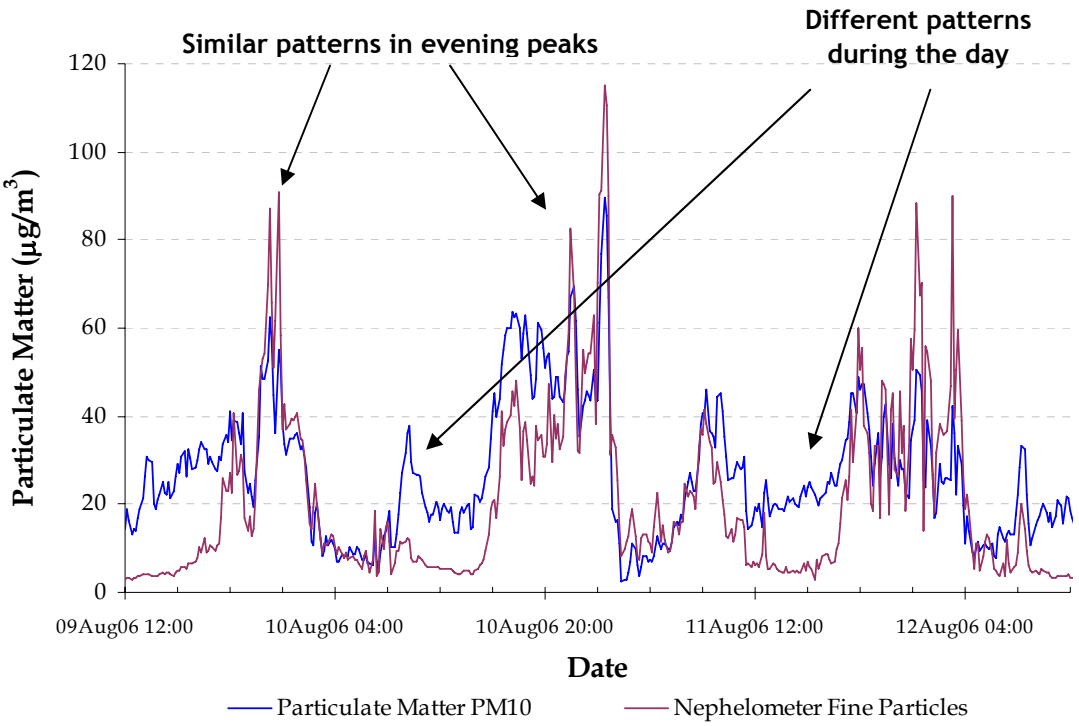

Figure 4 PM_{10} and $PM_{2.5}$ concentrations: 9-12 August, Woodside

Note: The method used to measure fine particles and PM_{10} are different, and as such the comparisons between fine particles and the $PM_{2.5}$ national standard cannot be made. The method used for fine particles only provides an estimation of the fine particle concentration. It should be noted that fine particle concentrations should not exceed PM_{10} concentrations, although due to the different measurement methods this can occur.

HOW DID WOODSIDE COMPARE WITH OTHER LOCATIONS IN ADELAIDE?

Particles

When comparing the particle concentrations measured at Woodside with other sites across the Adelaide metropolitan area, it can be seen that Woodside is influenced not only by localised sources but also by regional particle events. These are events that affect most or all sites in the air-monitoring network and are independent of localised sources.

An example of a regional event occurred from 12.30 am to 12 noon on 9 August 2006, highlighted in Figure 5. This event occurred during westerly winds that were reasonably strong and consistent throughout the day.

Based on measurements, it appears that the background concentration of particles in Woodside is lower than that of other sites in the Adelaide airshed, which is to be expected as there are fewer sources in and around the township. As seen in Figure 5, on 10 and 11 August the particle concentration falls to a background level of 6 $\mu g/m^3$. This compares with the Kensington monitoring site, the next highest background at 10–12 $\mu g/m^3$.

An example of a particle event only occurring at Woodside is also highlighted in Figure 5. During the evenings of 9–10 August the particle levels increased sharply as the wind speed dropped below one m/s. Under these conditions particles measured would be from a local source. These low wind speed conditions are similar to the example shown in Figure 3. The shapes of the peaks (very sharp) in the plot below also suggest a local source, showing rapid changes in concentrations due to changes in wind direction or emissions.

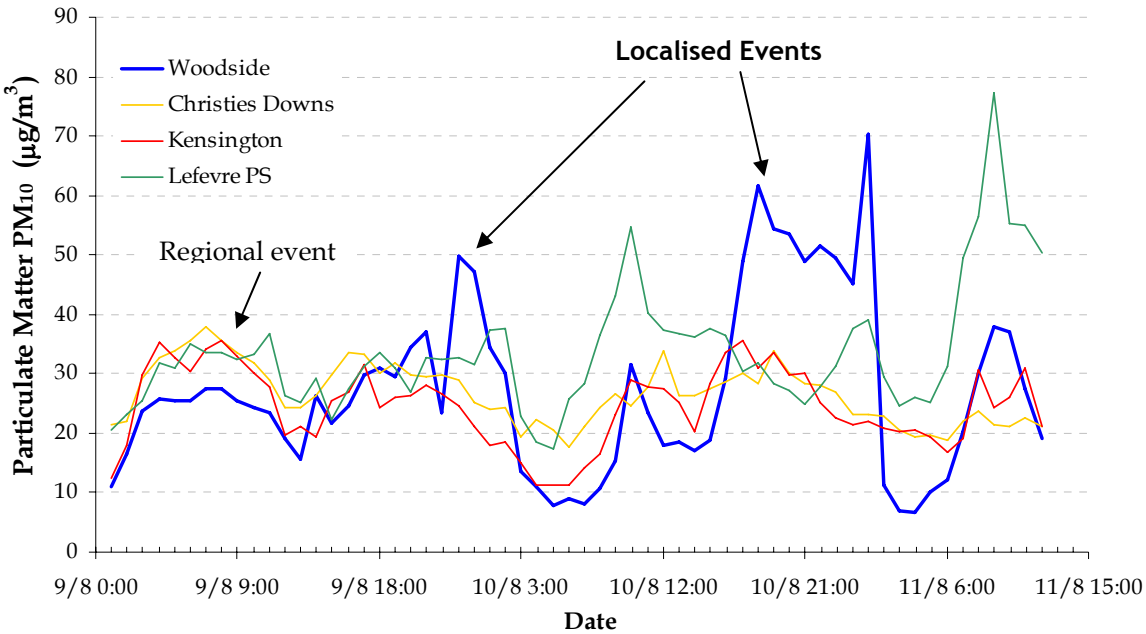

Figure 5 **Comparison of Woodside PM_{10} concentrations with PM_{10} concentrations measured at Christies Beach, Kensington, Le Fevre Primary School and Netley (not in graph) for the same time period, 9–12 August 2006, hourly averaged data**

Dust event

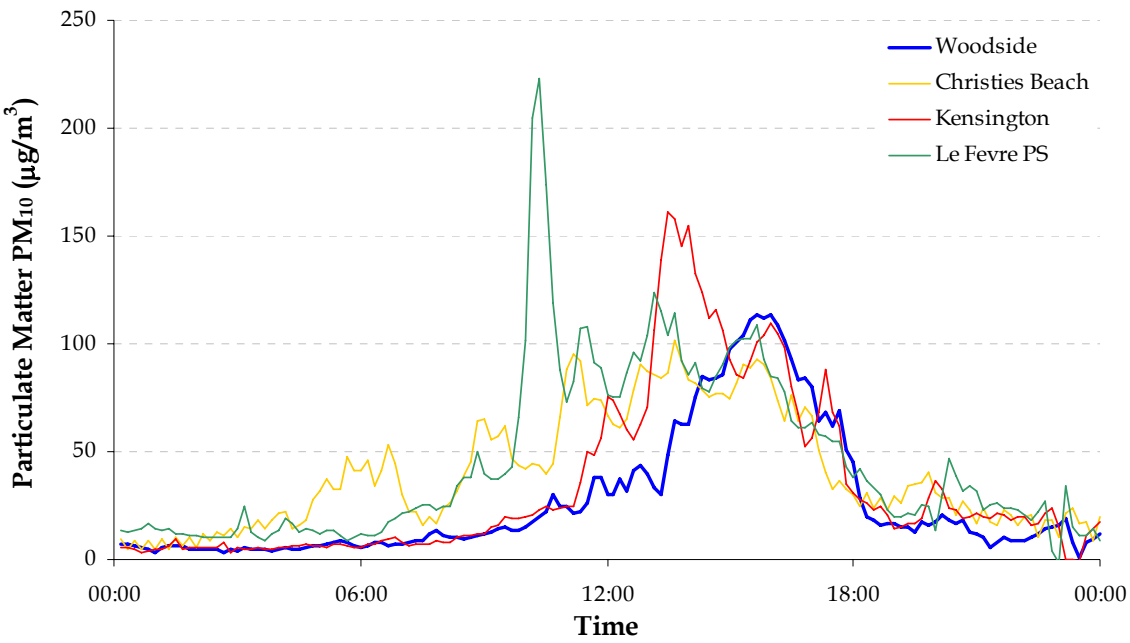

Figure 6 Dust event across the Adelaide metropolitan area and the impact on PM_{10} levels at Woodside, 10-minute data

Figure 6 shows a regional dust event which occurred on 16 August 2006 across the metropolitan Adelaide area, extending out to include Woodside. This highlights the fact that this particle event was transported during a regional weather event, with minimal impact from local sources.

The broad peak, lower magnitude and delay in measurement at Woodside compared with other sites shows the effect that transport has on particle pollution. These losses are from fallout and particles impacting upon surfaces, thus removing the dust from the air. The broadness of the peak shows that the event is not from a local source. The wind speed during this time was strong and from the west, which suggests that the effect of local particles would have been diluted and rapidly transported away from Woodside.

Carbon Monoxide (CO)

Woodside experienced higher CO concentrations when compared with another Adelaide residential site, Elizabeth Downs. Woodside experienced a maximum 8-hour averaged concentration that reached 19% of the national standard, while the 8-hour maximum for Elizabeth over the same time period was only 8%. These levels are low and well below the national standards.

Although very low at both sites, data showed the maximum level of CO measured at Woodside was on average found to be three times higher than at Elizabeth, where the site is open and not conducive to pooling of air.

This highlights the contribution that wood smoke makes to the concentrations of CO in a small township. If a larger population were present where wood smoke is the dominant pollutant, it is expected carbon monoxide would be higher than the anticipated levels in the metropolitan residential area where other heating such as natural gas and electricity are used.

DISCUSSION

Overall, the study provided a snapshot of wood smoke and a number of other air pollutants in an 'isolated airshed'. Of particular note is the dramatic dilution or transport effect that a small increase in the wind speed has on reducing airborne particle loadings. In addition, there were slightly increased levels of CO at Woodside when compared with another residential area in metropolitan Adelaide.

Fine particles were the major component of night-time particle pollution and this was almost exclusively derived from wood heating or burning activities in the Woodside area. Air monitoring data showed that the wood heaters did indeed account for the increase in particle pollution and some gaseous levels.

The opportunity for identifying an isolated environment where air pollution sources had minimal inputs from surrounding townships provided the EPA with a good case study to assess the effectiveness of the SmokeWatch education program and to develop identification techniques. The levels of pollutants measured in this study will serve as the initial and earliest baseline for the education program, while the levels measured in the winter of 2007 will provide an indication of improved awareness of efficient wood heater use.

This study provides an insight into the conditions necessary to pool wood smoke. It shows that, under the right meteorological conditions, the wood smoke produces short-term particle levels up to 100 $\mu g/m^3$ for a small residential township. This highlights that a township with minimal population and with approximately 400 homes can create marked winter air pollution. This information will allow an estimate of the population density required before detrimental air quality effects occur in an airshed. It also suggests that even small communities can experience significant degraded air quality if located where smoke can accumulate under still weather conditions.

The telephone survey results suggest that approximately 72% of people in the Adelaide Hills areas who use wood heaters are vigilant in ensuring that no unnecessary wood smoke is emitted. This is a high percentage and is a starting point that provides a good basis for improvement. It is hoped that, with information from this monitoring study, small improvements such as increased awareness and uptake of the principles outlined in the education program may yield cleaner overnight air quality.

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Further reading

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APPENDIX 1 MAP OF AIR MONITORING LOCATION

APPENDIX 2 INSTRUMENTS AND METHODS

Monitoring undertaken met relevant Australian Standards:

- TEOM 1400a Tapered Element Oscillating Microbalance
  As specified in AS 3580.9.8 – 2001
- ML9830 Carbon monoxide Direct Reading Method
  As specified in AS 3580.7.1 – 1992
- ML9841B Nitrogen Dioxide Chemiluminescence Method
  As specified in AS 3580.5.1 – 1993
- Radiance Research Nephelometer
  As specified in AS 2724.4 – 1987
- AR500 (DOAS) Differential optical absorption spectroscopy (DOAS) method
  Further information can be found at <http://www.opsis.se>.