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Dust deposition rates in the Wollongong-Port Kembla area, New South Wales, Australia

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Abstract

Dust deposition in the Wollongong-Port Kembla region, New South Wales, Australia, arising from local industrial and mining activities, has been of major concern since the early 1960s. Reports dealing with dust deposition rates in the region have been published by different organisations where the data have been averaged for the region. This provides a general trend for the deposition rates for the whole region without considering the trends occurring in specific locations. This study was the first to examine the trends observed at 35 individual gauges to identify more localised trends in dust deposition rates in the Wollongong-Port Kembla region, and also to try and identify the contribution of some of the possible dust sources. The coverage span of the data was from 1991-2003. These data were compared with two guidelines. The results indicated that the trend for dust deposition rates in the Wollongong-Port Kembla region is, generally, decreasing, but the patterns for different gauges varied both spatially and temporally. Several factors were suspected to influence dust deposition rates, including meteorological conditions, mainly wind direction, proximity to dust sources, dust control devices installed by industry, and other nearby activities that could affect the deposition rate measurements. Deposition rates in some residential areas exceeded the guidelines for recommended action. Further speciation and characterisation analyses of dust samples are needed to confirm their sources.

Keywords

Dust, deposition, rates, Wollongong, Port, Kembla, area, South, Wales, Australia

Disciplines

Life Sciences | Physical Sciences and Mathematics | Social and Behavioral Sciences

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ABSTRACT

Dust deposition in the Wollongong-Port Kembla region, New South Wales, Australia, arising from local industrial and mining activities, has been of major concern since the early 1960s. Reports dealing with dust deposition rates in the region have been published by different organisations where the data have been averaged for the region. This provides a general trend for the deposition rates for the whole region without considering the trends occurring in specific locations. This study was the first to examine the trends observed at 35 individual gauges to identify more localised trends in dust deposition rates in the Wollongong-Port Kembla region, and also to try and identify the contribution of some of the possible dust sources. The coverage span of the data was from 1991-2003. These data were compared with two guidelines. The results indicated that the trend for dust deposition rates in the Wollongong-Port Kembla region is, generally, decreasing, but the patterns for different gauges varied both spatially and temporally. Several factors were suspected to influence dust deposition rates, including meteorological conditions, mainly wind direction, proximity to dust sources, dust control devices installed by industry, and other nearby activities that could affect the deposition rate measurements. Deposition rates in some residential areas exceeded the guidelines for recommended action. Further speciation and characterisation analyses of dust samples are needed to confirm their sources.

INTRODUCTION

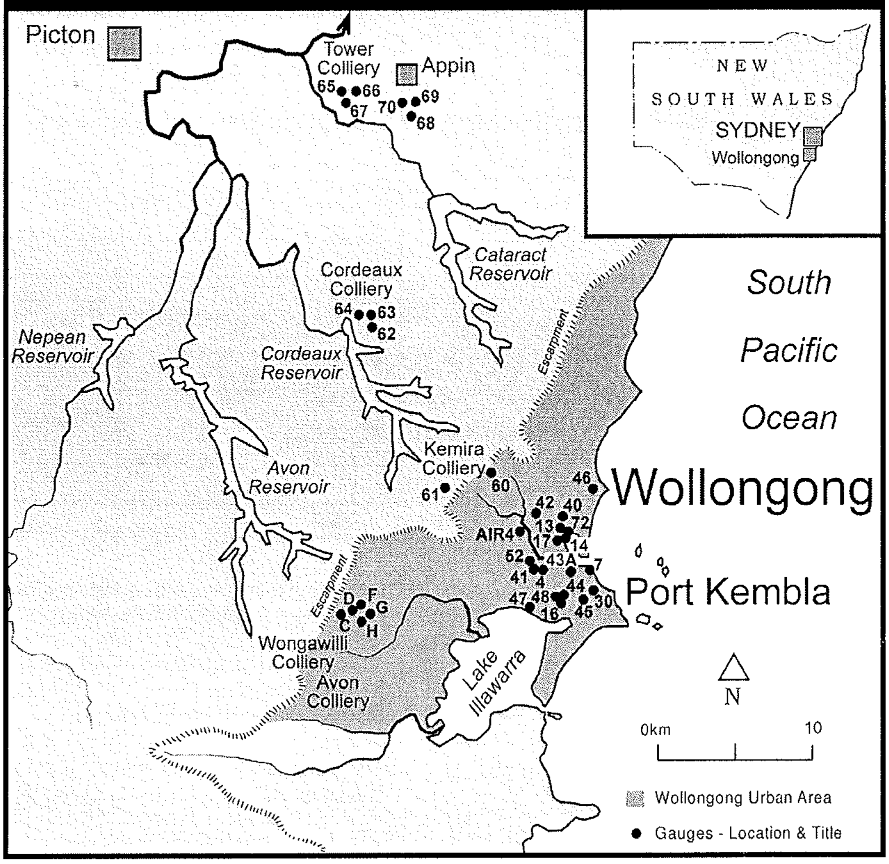
Wollongong and Port Kembla are part of the Illawarra region, New South Wales (NSW), Australia, which is characterized by its attractive environmental settings, including coastline, escarpment and inland plateau (SPCC 1986; Cardew & Fanning 1996; NSW EPA 1997). The Illawarra region is an important Australian centre for heavy industries such as steel works, copper smelting, coal mines and coke-works (SPCC 1986; NSW EPA 1997). These industries, along with the climate, geography and population density determine the magnitude of air pollution, e.g., dust deposition, in the Illawarra region, in general, and more specifically in the Wollongong-Port Kembla

Table 1. Seasonal climatic features in the Wollongong-Port Kembla area (adapted from Azzi *et al.*, 1998, and Miller & Morrison, 2000).

Season	Months	Average Daily Temperature	Wind Direction*	%Annual Rainfall**	Relative Humidity
Autumn	Mar; Apr; May	15-23°C	WSW; SW; SSW	30.1%	-
Winter	Jun; Jul; Aug	9-17°C	WSW; W; SW	21.8%	55-60%
Spring	Sep, Oct; Nov	14-22°C	NNE; WSW; NE	22.6%	-
Summer	Dec, Jan, Feb	19-26°C	NNE; NE; S	25.5%	75-80%

* Major wind directions in the season
**Total rainfall in the range 1000 (coast)-1500 (escarpment) mm yr^{-1} depending on

Figure 1. Locations of the dust deposition gauges in the Wollongong-Port Kembla area.



area (SPCC 1986; NSW EPA 1997, 2001a).

The air quality in the region has been a subject of constant debate for over 50 years and scientific measurements have been undertaken sporadically since the 1950s. Concerns about air quality and its impact on health have led to legislative and technological changes since the introduction of the NSW Clean Air Act in 1961. A relatively intensive investigation of dust in the local atmosphere began in the early 1990s with the setting up of numerous dust deposition gauges in the region, some managed by the NSW Department of Environment and Conservation (DEC, including the former Environmental Protection Authority, EPA) and some by local industry. Industry data are reported to the NSW DEC on a regular basis. BlueScope Steel Ltd. also monitors PM10 (one station) and TSP (two stations) and supports an Australian Nuclear Science and Technology Organisation (ANSTO) program monitoring PM2.5. Reports dealing with dust deposition rates in the region have been published by different organisations where the data have been averaged for the region. This provides a general trend for the deposition rates for the whole region without considering the trends occurring in specific locations. This study was the first to examine the trends observed at 35 individual gauges to identify more localised trends in dust deposition rates in the Wollongong-Port Kembla region. An attempt was also made to try and identify the contribution of some of the possible dust sources and factors that influence the deposition rates at different locations within the region.

MATERIALS AND METHODS

Study Site

The Wollongong-Port Kembla area, located at latitude around 34°36′S and longitude around 150°53′E, has a general elevation of about 10m above mean sea level, and the area is inhabited by about 200,000 people (NSW EPA 1997). The general climate of the area is warm coastal temperate with warm summers, cool winters and moderate to heavy (by Australian standards) rainfall throughout the year (Table 1). Local air movements are influenced by the proximity of the Tasman Sea to the east, and the regional topography which is dominated by the Illawarra escarpment rising to about 450m on the western rim of the region (Prescott, 1989).

The region is one of Australia's major heavy industry zones, including a large integrated steel works, the BlueScope (formerly BHP) Steel Company site, which is one of the largest industrial complexes in the southern hemisphere. These industrial activities have received significant attention from the relevant regulatory authorities, and improving air quality has been a high priority. The NSW DEC (which since 2004 incorporates the NSW EPA) regulates dust emissions (e.g., through licence conditions) and requires monitoring gauges to be located in the region along with process improvements to reduce dust deposition.

Table 2. Basic information about the 35 gauges selected for detailed study.

Gauge No.	Type of Location	Location
4	Residential	NSW DEC Air Quality Monitoring Station, Carlotta Crescent, Warrawong
7	Industrial	# 1 Lift Pump Station, BlueScope Steel, Port Kembla
13	Industrial	North Gate Security Office, BlueScope Steel, Port Kembla
14	Industrial	# 2 Products Berth Car Park, BlueScope Steel, Port Kembla
16	Residential	16 Blaxland Avenue, Warrawong
17	Industrial	Spares Area North, BlueScope Steel
30	Industrial	Clyde Carruthers Plant, BlueScope Steel, Port Kembla
40	Residential	19 Bridge Street, Coniston
41	Residential	28 Monteith Street, Cringila
42	Residential	25 Mount Street, Mount St. Thomas
43A	Industrial	Shell Oil, Flinders Street, Port Kembla
44	Industrial	BlueScope Printing Dept., Corner Wattle & Flagstaff Roads, Warrawong
45	Residential	69 Shellharbour Rd./18 Holman St (Mar 1999), Warrawong
46	Residential	13 Stewart St, Wollongong
47	Residential	41 Grandview Parade, Lake Heights
48	Residential	Scout Hall site, Flagstaff Road, Warrawong
52	Residential	Cringila Community Centre, 32 Lake Avenue, Cringila
60	Colliery	Kemira Valley Colliery East
61	Colliery	Kemira Valley Colliery West
62	Colliery	Cordeaux Colliery South
63	Colliery	Cordeaux Colliery North
64	Colliery	Cordeaux Colliery West
65	Colliery	Tower Colliery West
66	Colliery	Tower Colliery East
67	Colliery	Tower Colliery South
68	Colliery	Appin Colliery South
69	Colliery	Appin Colliery East
70	Colliery	Appin Colliery West
72	Industrial	Flat Products Car Park, BlueScope Steel, Port Kembla
AIR4	Industrial	A I R Unanderra
C	Colliery	Wongawilli Mine
D	Colliery	Wongawilli Mine Bins
F	Residential	Wongawilli Township (Behind School)
G	Residential	Shone Avenue, West Dapto
H	Residential	Bong Bong Rd, West Dapto

Dust deposition data

Dust deposition rates were measured as per the Australian Standard Method 2724.5, which is referred to as the "Particulate matter - determination of impinged matter expressed as directional dirtiness, background dirtiness and/or area dirtiness (directional dust gauge method)" (NSW EPA, 2001b). While dust deposition gauges are the simplest and the most commonly used air quality monitoring devices (Dombrowski *et al* 1995; Liu & Liptak 2000), the accuracy of the measurements obtained from these devices is limited due to their long measurement interval (usually one month), the effect of wind speed and direction, location selection and the size of the particulate matter (Cadel, 1975; Dombrowski *et al.* 1995; BHP 2000; Liu & Liptak 2000). These devices do not provide information on dust concentration in air nor will they specify directly the source of dust (Howard & Cameron 1998). Despite this fact, dust deposition gauges are useful in establishing long-term dust pollution trends in a given locality, and they can be useful in specifying the sources of dust emission through further physical and chemical analysis on the deposited matter in these gauges (Bardsley, 2000; Liu & Liptak 2000).

The data reported in this study were made available by BlueScope Steel Ltd. The dust deposition rates were measured in the Wollongong-Port Kembla area and around several colliery sites in the Illawarra region starting from about 1991. More than 6,000 data point sets were examined, consisting of information on insoluble solids and ash (mass remaining after heating the insoluble solids to 1000°C for 2 hours), reported in units of g m^{-2}/month.

Initially, data from 87 different gauges that varied in their monitoring duration from a few months to 13 years were examined. As patterns of change with time were of greatest interest, gauges with more than 100 total data points (i.e., at least eight years of data) were selected for further investigation. Data sets where more than two data points were missing in a given year were not considered other than for comparison with nearby gauges in examining seasonal patterns. 35 gauges (from the original number of 87) met these selection criteria, and the data from these gauges were further screened. These steps aimed to quantify missing data points and to spot inaccurate values such as negative values or data points having higher ash concentration than insoluble solids. These data points were regarded as additional missing data. All of these missing data were designated by an NR symbol when graphing the data. Where necessary for statistical analyses, NR points were considered as the average of the data points immediately before and after the missing point. A total of 4,351 data points, from the selected 35 gauges, representing 71 per cent of the total provided data points was used in the deposition rates trend analysis.

The 35 gauges selected for detailed data analysis are listed in Table 2, along with type of location (residential/industrial/colliery) and specific locations. The gauge locations are also shown in Figure 1.
The data were then sorted to give:

(a) a compilation of the months in which the selected gauges had a measured value;
(b) a sum the total quantity of insoluble solids of each selected gauge, per year. The summation results were then averaged in order to obtain the average annual dust deposition rate recorded by each gauge;
(c) a classification/grouping of the dust deposition rates by season, using the seasons listed in Table 1.

Data Analysis

Data points for each of the 35 selected gauges were examined for exceedences of the different NSW DEC (EPA) deposition rate guidelines. For each gauge, the monthly concentrations of insoluble solids and ash, measured in each month, were compared with the immediate action guideline of 10 g m^{-2}/month (this guideline is specifically targeted at deposition in residential areas) (SPCC, 1983). For 14 gauges, located in or close to residential areas around suspected dust emission sources, average annual dust deposition rates were also determined. These gauges were selected following NSW DEC guidelines. The average annual dust deposition values were compared with the NSW DEC (EPA) annual average dust deposition guideline of 4 g m^{-2}/month for residential areas (Young and Laird 1992; NSW EPA 2001b). Data were also examined to determine if exceedences could be related to factors such as local weather patterns (Perkins 1974; Azzi et al. 1998; Liu & Liptak 2000). Correlations were also completed between insoluble solids and ash contents, and trend lines of the deposition rates over time were also produced using a linear least squares process (a trend line was considered significant if $p < 0.05$). It should be noted that in some cases a significant trend may be the result of higher dustfalls in 2-3 years followed by lower values in later years without a distinct on-going trend.

Results and Discussion

Monthly Dust Deposition Rates

The deposition data are summarised in Table 3. The deposition patterns were sorted into two groups initially – those where the NSW DEC guideline for action (10 g m^{-2}/month) was never exceeded, and those where this value was exceeded. Seven gauges (numbers 40, 41, 42, 47, 48, 67 and G) showed no values above this guideline, and 28 showed at least one value above the action guideline (Table 3). Of the gauges showing no values above the monthly guideline, five were located in residential areas, with the other two (codes 67 and G) located near collieries (Figure 1). Further examination of the locations of the residential non-exceedence gauges showed that they are at least 1km from recognised major dust sources and some are also separated from sources by hills.

Of the 28 gauges showing values above 10 g m^{-2}/month, nine (numbers 4, 13, 30, 44, 45, 46, 63, 72 and C) exceeded this value on only one occasion. Interestingly, three of these gauges (13, 30 and 44) are located within the steel industry complex, although they are on the fringes of this zone. The gauges showing the largest numbers of values exceeding the guideline were numbers 7, 14, 16, 17, 43A, 60, 61, 65, 69 and F (although there is evidence that for gauge 16, tampering occurred in the period Oct 2001-May 2002). All the others had less than five values above this action trigger (or <5% of the time) (Table 4). Typical deposition data for the different patterns observed can be seen in Figure 2.

The nine gauges showing only one exceedence of the NSW DEC monthly guideline showed no particular patterns. The single exceedences occurred in different months and years, and several of these events were only just above the guideline, indicative of one-off occurrences. It should also be noted that the region experiences regular very strong winds and these may have contributed to the singular high deposition rates.

Further analysis of the data for the gauges showing the greatest number of exceedences was attempted. Gauges 7, 43A and 60 had the greatest number of exceedences, and these occurred throughout the study period. Gauge 7 is located close to a heavy industry area and is to the east of the one significant dust source (coal stockpiles and a coke works) such that it lies downwind in winter when the prevailing winds are from the south-west. This gauge showed the highest deposition rates in winter. Site 43A is also located close to heavy industry and to the east of major operations and stockpiles. Similarly to gauge 7, this gauge showed the highest deposition rates in winter when downwind of major dust sources. Gauge 60 was located adjacent to a colliery that ceased operations in 1991, so no specific cause of regular high dust deposition rates has been identified.

The other high exceedence number gauges gave above guideline values over more limited time frames. Gauge 16 showed exceedences only after October 1996, but many of these occurred during the time of suspected contamination and are not discussed further. Gauge 14 showed exceedences only after November 1996, and gauge 17 only after Jan 1996. Gauge 14, located within the steel industry complex, showed the highest values in summer, indicating likely sources to the north-east; possible sources include the construction works associated with the infilling of the western basin of Port Kembla Inner Harbour and the development of an adjacent multi-purpose berth. Gauge 17 is located in a significant materials stockpile area, and changes in area management including road alignments may have led to the changes in the dust deposition pattern. Gauges 61 (all exceedences except one between May 1996-November 1998), 65 (no exceedences after July 1996), 69 (most exceedences between March 1994-December 1996), and F (most exceedences between 1996-1999) are all located in areas around collieries, where the changes to mining regulations have led to reduced dust emissions and improved conditions for workers. These include the requirements introduced in the late 1990s for mining companies, under their mining leases, to produce annual reports, including data on dust deposition, and also to develop improved mining operations plans which included environmental protection measures (J. Ford, Mineral Resources Division, NSW Department of Primary Minerals, personal communication). Further examination of the colliery data by area, showed that the Kemira mine area showed many more exceedences that the Appin, Cordeaux, Tower, or Wongawilli sites. This may be related to the fact that for most of the study period, the Kemira mine was closed and therefore there would not have been any active program of dust suppression as would have occurred at the operational collieries (Holmes, 1990).

The data for gauges located in residential areas (4, 16, 40, 41, 42, 45, 46, 47, 48, 52, F, G, H) showed very few exceedences (apart from the suspected contamination at site 16). The only exception was gauge F located in Wongawilli township which showed 11 exceedences, a much higher number than shown by the gauges located adjacent to the local colliery (C and D). A possible explanation for this is the extensive movement of coal by trucks through the area, with less dust control than at the operational minesite.

When the trend lines are examined, four gauges gave statistically significant downward trends and four gave significant increasing trends. Of the other gauges that showed any exceedences of the DEC monthly guideline, the majority (70%) showed non-significant deceasing trends.

Average Annual Dust Deposition Rates

As noted earlier, average annual dust deposition rates were also determined for a selected set of 14 gauges. Using the NSW DEC (2001b) guideline for annual average dust deposition rate of 4 g m^{-2}/month, three gauges (42, 47, G) never exceeded the guideline, three gauges (40, 41, H) exceeded the guideline in only one year, three gauges (45, 46, 48) exceeded in 2 years, one gauge (F) exceeded the guideline in three years, three gauges (44, 52, AIR4) exceeded the guideline in five years, while gauge 43A exceeded the guideline in all 10 years when measurements were made.

For those gauges that exceeded the average annual guideline, most exceedences were in the early or mid-1990s. The exceptions were gauge 44 (exceeded in 2003), gauge 46 (exceeded in 2002) and obviously gauge 43A (all years from 1994-2003). This pattern is consistent with the improvements made in air quality management in the region during the 1990s, including stockpile dust suppression systems, dust collection systems in manufacturing units, and closure of older manufacturing facilities.

Looking at the geographic location of these gauges with respect to the Port Kembla industrial area, three gauges located to the north (40, 42 and 46) showed minimal exceedences of the annual average guideline (40 had one exceedence, 42 had zero, and 46 had two). These gauges showed no significant trends with time and no links of depositional patterns to seasonal wind patterns. Three gauges located to the west of the industrial area (41, 52 and AIR4) showed greater numbers of exceedences (41 had one exceedence, 52 and AIR4 each had five). There were no significant trends over time, but higher deposition rates were measured in spring and summer when north-easterly winds prevail and these sites are located downwind of coal storage areas. Almost all the exceedences occurred prior to 1998, by which time many dust reduction programs had been implemented.

Five gauges were located south of the Port Kembla industrial area (43A, 44, 45, 47, 48). Of these gauges, 47 showed no exceedences of the average annual guideline, 45 and 48 had two, 44 had five, and 43A had 10. Gauges 43A and 45 showed significant decreasing deposition trends with time, while the others showed no significant trends. Most showed higher deposition rates in spring and summer, which could be linked to the fact that they are located downwind of the industrial zone in those seasons. The

Figure 2. Typical monthly data for selected dust deposition gauges; Gauge 4, minimal exceedences of the NSW DEC Guideline of 10 mg m^{-2} mon^{-1} and an overall decreasing trend; Gauge 14, significant number of exceedences with an increasing trend; Gauge 41, no exceedences of NSW EPA Guideline; Gauge 43A, significant number of exceedences with a decreasing trend.

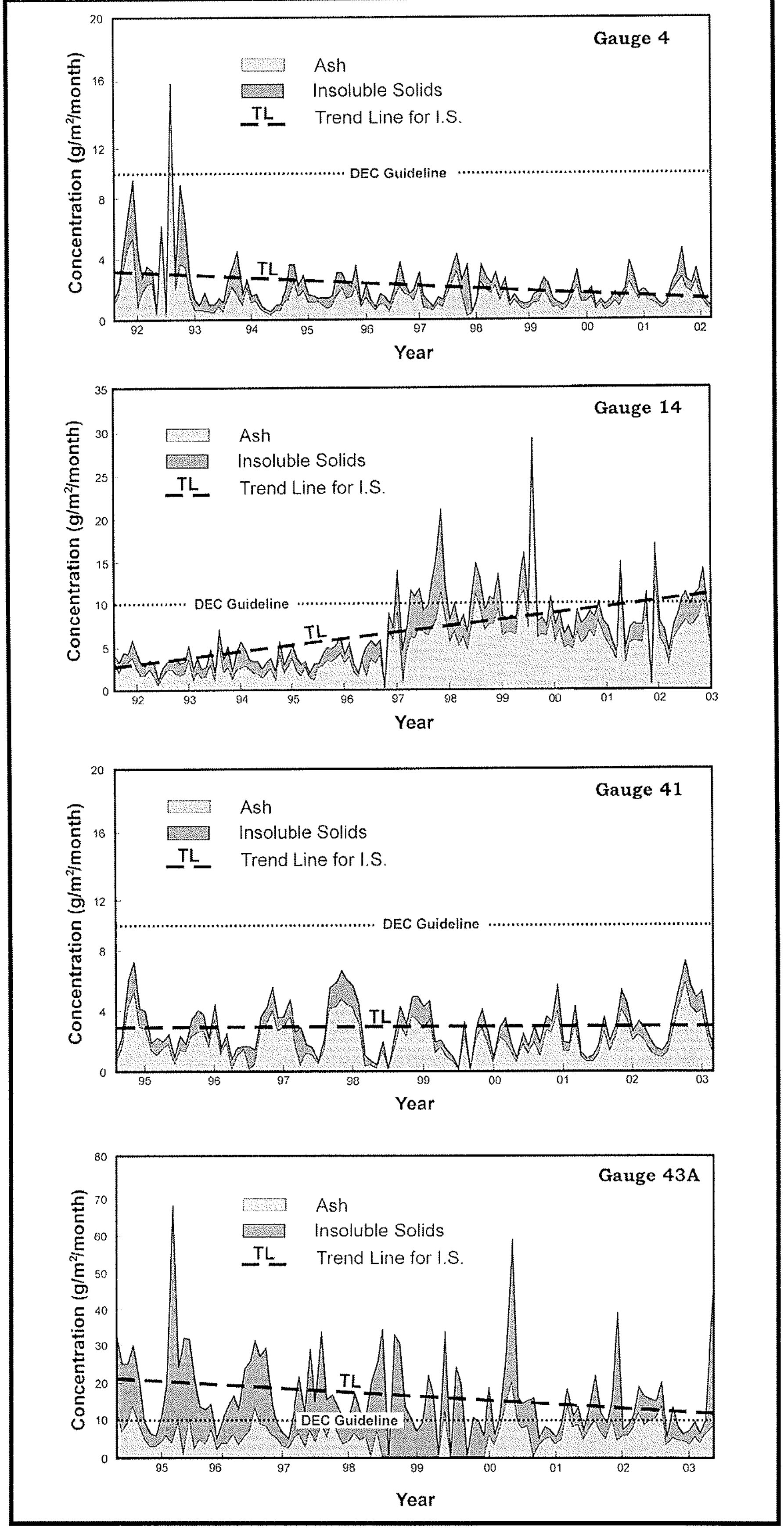


Table 3. Data derived from the basic analysis of the dust deposition rates

Gauge No.	Total Years of Data	No. Data points used in Analysis	No. of Exceedences of NSW DEC Monthly Guideline*	% Exceedences	Max. Insol. Solids g m^{-2} mon^{-1}**	Month of Highest Deposit.	Ash as% Insol. Solids (Avge)	General Trend++
4(R)	13	126	1	<1	16	Oct92	93	SDT, highest values in Summer
7	13	134	82	61	76	Apr98	71	SIT, highest values in Winter
13	13	138	1	<1	11	May00	90	NST, highest values in Summer
14	13	138	26	19	29	Mar00	97	SIT, highest values in Summer
16(R)	11	71	15#	21#	1252#	Apr02#	98	NST if likely contaminated samples ignored, highest values in Summer
17	13	131	28	21	21	Aug00	95	SIT, highest values in Summer
30	13	135	1	<1	22	Jun00	62	NST trend, highest values in Autumn
40(R)	13	133	0	0	8	Feb01	91	NST, highest values in Summer
41(R)	10	99	0	0	8	Dec02	98	NST, highest values in Summer
42(R)	13	133	0	0	6	Feb93	90	NST, highest values in Summer
43A	10	88	62	70	68	Apr95	59	NST, highest values in Winter
44	13	135	1	<1	22	Jun00	82	NST, highest values in Summer
45(R)	13	133	1	<1	23	Sep91	96	SDT, highest values in Summer
46(R)	13	128	1	<1	15	Sep91	91	SIT, highest values in Spring
47(R)	13	135	0	0	7	Jan98	88	NST, highest values in Summer
48(R)	13	134	0	0	9	Feb98	91	NST, highest values in Summer
52(R)	11	105	2	2	33	Mar94	96	NST, highest values in Spring
60	13	117	58	50	76	Oct96	84	NST, highest values in Spring
61	13	120	16	13	310	Oct97	96	NST, highest values in Winter
62	13	132	3	2	59	Jun99	94	NST, highest values in Autumn
63	13	133	1	<1	21	Nov02	98	NST, highest values in Summer
64	13	132	2	2	33	Apr99	62	SDT, highest values in Summer
65	13	135	12	9	28	Aug95	79	SDT, highest values in Spring
66	13	130	3	2	33	Jun94	97	NST, highest values in Winter
67	13	130	0	0	10	Mar97	84	NST, highest values in Summer
68	13	134	3	2	184	Dec97	99	NST, highest values in Spring

Table 3. Continued

Gauge No.	Total Years of Data	No. Data points used in Analysis	No. of Exceedences of NSW DEC Monthly Guideline*	% Exceedences	Max. Insol. Solids g m^{-2} mon^{-1}**	Month of Highest Deposit.	Ash as% Insol. Solids (Avge)	General Trend++
69	13	137	9	7	62	Sep94	91	NST, highest values in Spring
70	13	135	4	3	17	Aug97	93	NST, highest values in Summer
72	11	99	1	1	12	Oct02	92	NST, highest values in Summer
AIR4	11	98	5	5	19	Dec96	89	NST, highest values in Spring
C	13	117	1	<1	11	Apr99	74	NST, highest values in Summer
D	13	128	3	2	22	Oct96	91	SDT, highest values in Spring
F(R)	13	124	11	9	30	May99	88	NST, highest values in Summer
G(R)	13	128	0	0	10	Feb01	81	NST, highest values in Summer
H(R)	13	126	2	2	37	Apr92	43	NST, highest values in Summer

(R) = Residential area *NSW DEC monthly action trigger = 10 g m^{-2} mon^{-1} **to nearest whole number
#Evidence of contamination (Oct01-May02) ++NST=no significant trend, SIT=significant increasing trend, SDT significant decreasing trend

exception was gauge 43A which gave the highest depositions in winter. As discussed above, this gauge is surrounded by industrial dust sources and could receive dust from different sources in different seasons. The fact that gauge 47 never exceeded the guideline may be related to the fact that it is the located further south of the industrial area than any of the other gauges in this group.

Examination of trend lines for average annual deposition rates showed that while 10 gauges (71%) showed decreasing trends, only one (43A) showed a statistically significant decreasing trend line.

Other Outcomes

An analysis of the frequency of exceedences (of the 10 g m^{-2}/month guideline) by month, showed that September was the month in which most exceedences (45) occurred during this study period, and February was the month of least exceedences (14). This is in line with the local weather patterns which show that February is one of the wettest and least windy months and September is the driest and one of the windiest months (BoM, 2006). The general weather patterns would thus support dust mobilization in September and limit it in February. In addition, it should be noted that during the period 2000-2003, much of NSW was in a drought. This would have impacted on the capacity of industry to keep stockpiles moist, and could have contributed to some upward trends for sites adjacent to stockpiles in the latter part of the study.

While no attempt was made to specifically identify dust composition in this study, examination of the ash as a percentage of total insoluble solids showed interesting points. For most gauges, the average ash/IS was over 80%, with only gauges (20%) showing values below this value. Of these, four gauges (64, 65, C and H) are located near collieries where coal particles would be expected to be a significant component of the dust and this component would exhibit major weight loss during ashing. Gauges 7 and 43A are located very close to major coal storage/handling/coking facilities where again coal materials would be expected to be a significant dust component. Gauge 30 is in the same vicinity but further away from the coal/coke sources than gauges 7 and 43A, and there is no other obvious reason for the low ash/IS percentage at this site.

The data also clearly show the importance of long-term data collection to ascertain dust deposition patterns. For example, gauge 14 showed no exceedences in the period 1991-1997, but 25 exceedences between 1998-2003, so that terminating collection of data in 1997 would have given a misleading indication of dust status. Conversely, gauge 65 showed 12 exceedences between 1991 and 1996, and 0 from 1997-2003.

Comparison of the data collected for the Wollongong-Port Kembla area with values from other locations show similar values to elsewhere. Capper et (1989) stated that for the UK, typical average values were 1.5 g m^{-2}/month for open country, 3 g m^{-2}/month for commercial centres of urban areas, and 4.5 g m^{-2}/month for industrial areas. Interestingly, Marx and McGowan (2005) report deposition rates for 0.02-11.9 g m^{-2}/month for rural areas on the west coast of New Zealand's South Island, and Pye (1987) reported rates varying from <0.25-50 g m^{-2}/month for arid and semi-arid areas around the world. For NSW, typical background values range from 0.8-8.1 g m^{-2}/month for agricultural areas (Green *et al.*, 2006), down to <0.1-1 g m^{-2}/month for isolated high ground areas (Johnston, 2001). Thus it can be seen that the Wollongong-Port Kembla data are typical of many urban areas, but the maximum values for many gauges (6-37 g m^{-2}/month) are above those considered acceptable on health grounds around the world (6-16 g m^{-2}/month, Vallach and Shillito, 1998).

CONCLUSIONS

This study indicates that there is a general decreasing trend in dust deposition rates in the Wollongong-Port Kembla area of NSW. Four sites exhibit statistically significant increasing trends, four a decrease and the remainder with guidelines exceedences trending downwards but not meeting the statistical significance test. Trending of PM10 and PM2.5 data (BlueScope Steel Ltd, personal communication, 2006) supports this conclusion. Guideline values, both on a monthly basis and on an annual average basis, were still exceeded frequently for some sites. This is despite ongoing efforts to reduce dust emissions through legislation and improvements in materials handling technology. More detailed information on the sources of dust is being researched in an ongoing project where collected samples are being subjected to microscopic and chemical analysis. Additional improvements that could be made include the use of wind directional gauges, more detailed recording of special meteorological events, and the education of the public about the problems caused by deliberate contamination of gauges. Extensive tree planting has already occurred around industrial complexes in the region, but more planting around the southern edges of the industrial area could assist in further reducing dust transport to nearby residential areas.

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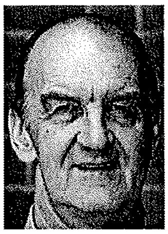

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