

Environment Protection Authority

Air quality in the Lower Lakes during a hydrological drought

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Abbreviations

AWQC	Australian Water Quality Centre
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DENR	Department of Environment and Natural Sources
EPA	South Australian Environment Protection Authority
HiVol	high volume dust units
Metals	
Al	aluminium
As	arsenic
Cd	cadmium
Co	cobalt
Cr	chromium
Cu	copper
Fe	iron
Mn	manganese
Ni	nickel
Pb	lead
V	vanadium
Zn	zinc
PM₁₀	Particles with 10 micron or less effective aerodynamic diameter
µg/m³	micrograms per cubic metre
µg/g	micrograms per gram
WSC	Water Security Council
WSTWG	Water Security Technical Working Group

Executive summary

Large areas of sediment were exposed in the Lower Lakes during 2007–10 during an unprecedented hydrological drought in the Murray–Darling basin. Many of these exposed sediments contained acid sulfate soils which had low pH levels (pH<4) and acidic minerals. There were government and community concerns about possible human health risks arising from exposure to dust blown off the dry and acidic lake beds.

The Environment Protection Authority (EPA), with guidance and funding from the State Water Security Technical Working Group and Council, initiated a study to monitor potential drought-related air quality impacts on the health of the Lower Lakes communities.

The initial study locations for air-borne dust monitoring were the Lower Lakes communities of Goolwa and Meningie (Stage 1). Rainwater quality testing (Stage 2) was carried out in these and additional locations (Clayton, Milang and Strathalbyn) and Stage 3 focused on dust sampling at Milang and Meningie whilst also including a rainwater tank sampling program in the region of the Lower Lakes.

High-volume dust sampling units were installed to activate at a wind velocity of 2 m/s within a specified angle range (off exposed lake beds) to capture airborne dust particles on a filter. Dust particles found on the filters were sent to laboratories for analysis of health related parameters including particle concentration, pH/acidity, metals, metalloids, mineralogy, and in some cases metal speciation.

Rainwater sampling was conducted at various Lower Lakes communities (Goolwa, Hindmarsh Island, Meningie, Milang and Clayton) including control samples at Strathalbyn. Water samples were analysed by the Australian Water Quality Centre (AWQC) for pH, metals (total Al, As, Cu, Fe, Pb, Zn), alkalinity, sulfate, chloride, and nitrate.

The main findings of the study were:

Stage 1

- The dust on the filters in the preliminary sampling (Stage 1 sampling) was found to be non-acidic. A health risk assessment on the metals results contained in Appendix 2 by Golder Associates (2008) indicated 'ambient air levels of metals in Meningie and Goolwa are unlikely to be a cause for concern for the health of residents who might be exposed'. However it was noted that there were still significant uncertainties that needed to be addressed to confirm this assessment.

Stage 2

- Rainwater tank results also showed no distinct differences between the tanks subjected to dust from the exposed lake beds and the control tanks from Strathalbyn. SA Health, who has advised the EPA that the results obtained are 'of no concern and will have no implications to human health'.

Stage 3

- Relatively low levels of particles were found on the filters at the Lower Lakes sites. Particle monitoring conducted in the same time period in the Adelaide region resulted in 20% higher concentrations of PM₁₀ particles than the Lower Lakes sites.
- Neutral pH recordings (9–11) on the particles confirmed low acidity.
- Very little difference was found between particle or metal levels at Meningie and Milang.
- All metals tested (except chromium) were well below the guidelines for metals in air, as defined by the Health Reference Values for Metals in Air (Golder 2008)
- Chromium speciation was undertaken to determine if chromium III (low toxicity form of chromium) was the dominant species; this was confirmed to be the case.

- CSIRO mineralogy analysis of the filters showed low levels of acid sulfate soil minerals, mostly sand (quartz) and salt (halite). This supported the above findings of low acidity or metal content.
- There was no indication of any increased risk to drinking rainwater from tanks within the Lower Lakes region during the drought, and it was the same for the tanks within the immediate Lower Lakes region and the control tanks from Strathalbyn. This was again consistent with the results obtained from the sampling conducted in Stage 1 (2009).

Based on these results, SA Health has stated that 'these (Stage 3) results and the chromium speciation analyses confirm the previous assessment that the dust does not represent a significant risk to public health in terms of acidity or heavy metals'.

In conclusion, multiple lines of evidence show no indications of a risk to human health due to dust blown off the exposed bed of the Lower Lakes.

Despite these findings of low health risk, the Lower Lakes community has likely experienced an increase in nuisance dust during the drought, and it is recommended that future water management strategies should consider this issue.

1 Introduction

The Murray–Darling Basin has been experiencing the worst hydrological drought conditions on record. The prolonged low flows out of the Murray–Darling catchment from 2007–09 were insufficient to counter evaporative losses from the large (88,000 ha) and shallow Lower Lakes. The consequence of this was that water levels fell over 1.5 m from pre-drought levels reaching approximately one metre below sea level in late 2009.

The lowering water levels have resulted in the extensive exposure of acid sulfate soils (Fitzpatrick *et al* 2008, 2010). Acid sulfate soils accumulate under waterlogged conditions where there is a supply of sulfate, the presence of organic matter that can be metabolised and iron containing minerals. These sulfide minerals are generally stable under waterlogged (reducing) conditions, however, on exposure to air the acidity produced from sulfide oxidation can impact on soil quality, water quality, crop production and corrode concrete and steel structures (Dent 1986). The acidification of soils can also result in the mobilisation of other potentially toxic metals and metalloids (Simpson *et al* 2010).

The community raised concerns that they could be exposed to acidic and/or toxic dust as a consequence of exposure of large areas of lake bed. Figure 1 shows the exposed bed of Lake Albert at Meningie and a dust storm event at Goolwa on 22 January 2009.



Figure 1 Lake Albert in Meningie and Goolwa Channel, January 2009

There was no information available on potential human health risks arising from dust exposure in the region although risks have been noted elsewhere in Australia (Ljung *et al* 2009, 2010). A screening level human health risk assessment undertaken by Golder Associates (2008) rated the likely risks to human health arising from acid sulfate dust exposure below Lock 1 as low. However this assessment was not based on direct dust measurements so a high level of uncertainty existed. Given the findings of very acidic exposed lake beds and increasing community concerns on this issue it was considered imperative that data should be collected to improve the human health risk assessment.

Project aims

The aim of the project is to assess the potential human health risks arising from the drying and wind mobilisation of acid sulfate soils around the Lower Lakes.

The general scope of the project is defined by the requirements of the Water Security Technical Working Group (WSTWG) for the Water Security Council (WSC) to understand drought-related impacts on community wellbeing and livelihood, particularly below Lock 1 where large water level declines were evident. Water level management is a key component of several projects and strategies managed by the WSTWG and WSC. The lake level influences the amount of exposed sediment present, and thus the potential dust risk to the community.



Figure 2 Map of dust monitoring sites in the Lower Lakes region 2009-10

2 Monitoring and data collection

The general study location was in the communities surrounding the Lower Lakes, Lake Albert and Lake Alexandrina (Figure 2). The initial study locations for air-borne dust monitoring were the Lower Lakes communities of Goolwa and Meningie (Stage 1). Rainwater quality testing (Stage 2) was carried out in these and additional locations (eg Clayton, Milang and Strathalbyn). Stage 3 focused on dust sampling at Milang and Meningie whilst also including another rainwater tank sampling program.

Stage 1–Dust monitoring 2009

Two high volume ‘Wind Switched’ air samplers (HiVols) were installed at Goolwa and Meningie (Figure 3). These units pump large volumes of air through filters and were set to activate at a wind velocity of 2 m/s within a specified angle range (off exposed lake beds) as specified below:

- Goolwa: northerly to southerly winds (0 to 180 degrees–easterly arc)
- Meningie: southerly to north–easterly winds (180 to 45 degrees–westerly arc)

The HiVol filters collect dust up to PM_{10} fraction size (particles measuring 10 μm or less). PM_{10} is commonly identified as particles likely to be inhaled into the lungs of humans, thus posing a potential health risk. Particles greater than PM_{10} can also be trapped in the throat and nasal passages and depending on the composition of the dust, can cause nuisance and irritation to humans.

Filter transactions occurred every two weeks, or when the airflow through the filter dropped below 65 m^3 per hour. The collected filters were sent to Ecotech Melbourne for weighing and sent to EML Air Emission Testing for metals analysis. Testing included chemical analysis of the filters for total dust concentration (PM_{10} fraction), acidity (wet paste pH), and metals and metalloids (total arsenic, cadmium, cobalt, chromium, copper, manganese, nickel, lead, vanadium, zinc, aluminium and iron). Sub-samples of selected filters were also sent to CSIRO for X-ray diffraction analysis to assess dust mineralogy and the relation to their characterisation of acid sulfate soil sediments in the lakes



Figure 3 HiVol unit at Goolwa

Stage 2–Rainwater sampling 2009

Sampling was carried out on 27 April 2009, following a rain event that would have washed dust from the roof catchments. This was the first substantial rain event after the dry summer period so was likely to have contained several months of dust build-up. A total of 18 rainwater tanks were sampled in Meningie, Milang, Clayton, Goolwa and Hindmarsh Island, with a further two samples taken from Strathalbyn as controls. Tanks were sampled from the entry point to the tank, using a bucket and rope to avoid metal contamination caused by piping or metal sampling rods (Figure 4). Water samples were

also collected from household taps in the region and analysed by the Australian Water Quality Centre (AWQC) for pH, metals (total Al, As, Cu, Fe, Pb, Zn), alkalinity, sulfate, chloride and nitrate. Concentrations were compared to guideline levels. The roof and pipe material and condition were noted at each site to assess the likelihood of other sources of metals being present in tanks due to leaching and corrosion.



Figure 4 Rainwater tank sampling, Meningie 2009

A risk-assessment workshop was conducted on 1 July 2009 involving SA Health, Department of Environment and Natural Resources (DENR), Golder Associates and EPA to analyse and review the results of Stage 1 and 2. An independent risk assessment by Golder Associates presented at this meeting indicated 'ambient air levels of metals in Meningie and Goolwa are unlikely to be a cause for concern for the health of residents who might be exposed'. However there were uncertainties in this assessment as it was based on limited data. From this workshop it was determined further dust monitoring (Stage 3) should be undertaken with a focus on the assessment of concentrations of metals (aluminium, nickel, chromium and arsenic), pH and acidity in dust blown from the Lower Lakes in the summer of 2009–10. A rainwater tank sampling program would also be included in Stage 3.

Stage 3–Dust and rainwater sampling 2009–2010

Stage 3 sampling was undertaken for a six month period from 3 November 2009 up to 2 May 2010. Two wind switched sampling units were installed at Meningie and Milang to collect dust particles (PM₁₀ fraction) blowing off the exposed lake beds of Lake Albert and Lake Alexandrina respectively. These units were set to activate at a wind speed of 2 m/s and to the following wind directions:

- Meningie: southerly to north–north–easterly winds (180 to 20 degrees–westerly arc)
- Milang: north–easterly to southerly (50 to 190 degrees–easterly arc).

The sample filters for the units were changed approximately every two weeks.

An additional high volume sampler was also installed at each site to sample continuously for a full day every sixth day (Figure 5). This method allowed for the assessment of windblown dust from the general land area (agricultural land, township, etc) compared to that from the exposed lake beds.

Gravimetric analysis was conducted on the sample filters at the EPA laboratory at Netley for total PM₁₀ particle concentration. Sections of filters were sent to Queensland Health laboratories for aluminium, nickel, chromium, arsenic and pH analysis. Additionally the first eight samples were analysed for the full suite of 12 metals (total As, Co, Cd, Cr, Cu, Mn, Ni, Pb, V, Zn, Al, Fe). Based on an initial set of results it was decided to test only filters with high particle levels (>20 µg/m³).

To ensure quality assurance and transparent calibration to Australian Standards, the following procedures and protocols were followed:

- Calibrations of temperature, pressure and flow using calibrated traceable equipment
- Correct weighing procedures of filters for high-volume sampling
- The determination and testing of filter blanks as batch blanks and field blanks
- The calibration of meteorology sensors
- Flow and mass calibration (using traceable calibrated equipment) for 24-hour monitors
- Two years retention of filters not sent for analysis.

Eight samples plus one background field blank were also sent to CSIRO for bulk qualitative X-ray diffraction analysis (XRD). CSIRO also analysed archival surface soil samples for speciation from areas of the lake bed around Milang and Meningie.



Figure 5 Two HiVol units (one wind switched and one 24-hour) installed at Milang

Rainwater sampling was conducted again on 18 May 2010 to assess any changes which may have been a result of increased acid sulfate dust mobilisation following a dry summer period with low lake levels. A total of 18 tanks were sampled from Meningie, Milang, Clayton, Goolwa and Hindmarsh Island, including two control tanks from Strathalbyn. The tanks were once again sampled from the entry point to the tank, using a bucket and rope to avoid metal contamination caused by piping or metal sampling rods.

Odour (sulfur gas) monitoring was considered as an option due to some noticeable odours in the Goolwa channel area; however these odours dissipated with inflows into the Goolwa Channel and testing was not implemented.

3 Results and discussion

Stage 1

The dust on the filters in the preliminary sampling (Stage 1 sampling) was found to be non-acidic. A health risk assessment on the metals results contained in Appendix 2 by Golder Associates (2008) indicated 'ambient air levels of metals in Meningie and Goolwa are unlikely to be a cause for concern for the health of residents who might be exposed'. However, there were a number of uncertainties noted that need to be addressed. These include uncertainties about the air monitoring analytical results, speciation of chromium, and variability of particle and metal concentrations in different seasons and different locations.

CSIRO mineralogy results (Table 1) showed limited amounts of acid sulfate soil minerals in the dust on the filters, mostly sand (quartz), and salt (halite). These findings are consistent with the low levels of acidity and metals noted earlier.

Table 1 Mineralogical composition of Lower Lakes dust samples 2009

Sample ID and location	Mineralogical composition
T-00783 Meningie	Halite (NaCl)–dominant; Gypsum (CaSO ₄ .2H ₂ O)–sub-dominant
T-00788 Goolwa	Halite–dominant; Gypsum–minor; Quartz, feldspar (albite) and possible natrojarosite–trace
T-00786 Meningie	Halite–dominant
T-00887 Goolwa	Halite–dominant, Gypsum–minor

*dominant (>60%), co-dominant (sum of phases >60%), sub-dominant (20-60%), minor (5-20%), trace (<5%)

Source: Fitzpatrick *et al* 2009

Stage 2

The results from rainwater quality testing indicated pH levels ranging from 6.4 to 7.7 which are typical values for fresh rainwater. Both nutrients and metals were well below the values contained in the Australian Drinking Water Guidelines (NHMRC 2004), with exception to zinc which in a few circumstances showed an exceedence of the aesthetic guideline (based on taste). There is no health limit for zinc. The high zinc samples were taken from zinc galvanised or zincalume tanks, roofs or gutters. Colorbond or tiled catchments and polyethylene tanks resulted in much lower zinc concentrations. Sulfate concentrations ranged from 2.7 mg/L to 12.6 mg/L, well below the drinking water guidelines (250 mg/L).

Results also showed no distinct differences between the tanks subjected to dust from the Lower Lakes and the control tanks from Strathalbyn. The results were examined by SA Health, who has advised the EPA that the results obtained were of no concern and will have no implications to human health.

Stage 3

The laboratory results from Stage 3 were compared with the Health reference values for metals in air collated by Golder Associates (2008), shown in Appendix 2. Selected results (for PM₁₀, pH, aluminium, chromium) are shown in Figures 6–9 against the relevant guideline (indicated by red dashed lines). These results indicated:

- Relatively low levels of particles, only nine filters out of 92 had particle levels >20 µg/m³ (trigger for additional analyses) and all samples were below guidelines (Figure 6).

- There was no evidence of acidic particles as all pH recordings were in the 9–11 range, similar to the blank filter levels (Figure 7).
- Consistently low aluminium levels were found, peaking at $1.94 \mu\text{g}/\text{m}^3$, well below the reference value of $5.2 \mu\text{g}/\text{m}^3$ (Figure 8).
- Chromium exceeded guideline levels but these results were not related specifically to acid sulfate soils due to the 24-hour results comparing similarly to the wind switched results off the lake bed (Figure 9). Archival surface soil samples from the lake bed were examined by CSIRO for speciation of chromium. It was found that chromium III (low toxicity form of chromium) was the dominant species with very low levels (almost undetectable) of the more toxic chromium VI species (Table 2).

The results for other metals (Appendix 3) also indicate no exceedence of guidelines and very little difference between dust levels or metal levels between the two sites. There was marginal difference between wind switched samples and 24-hour samples for metals or dust. If metals were evident in the dust from the wind-switched units then the metal concentrations in this dust would be higher than that found by samplers collecting dust from all directions (24-hour samples).

Based on these results, SA Health has stated that 'these results and the chromium speciation analyses confirm the previous assessment that the dust does not represent a significant risk to public health in terms of acidity or heavy metals'.

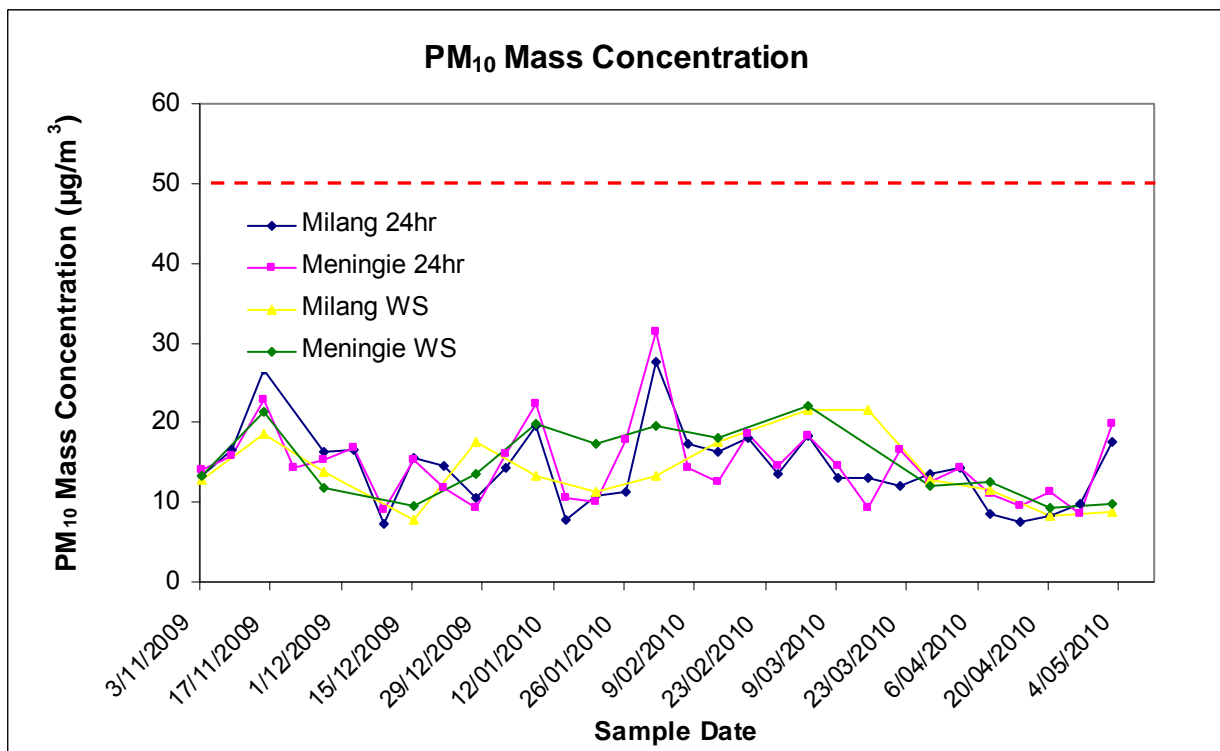


Figure 6 Total particle load on filters, Milang and Meningie 2009–10

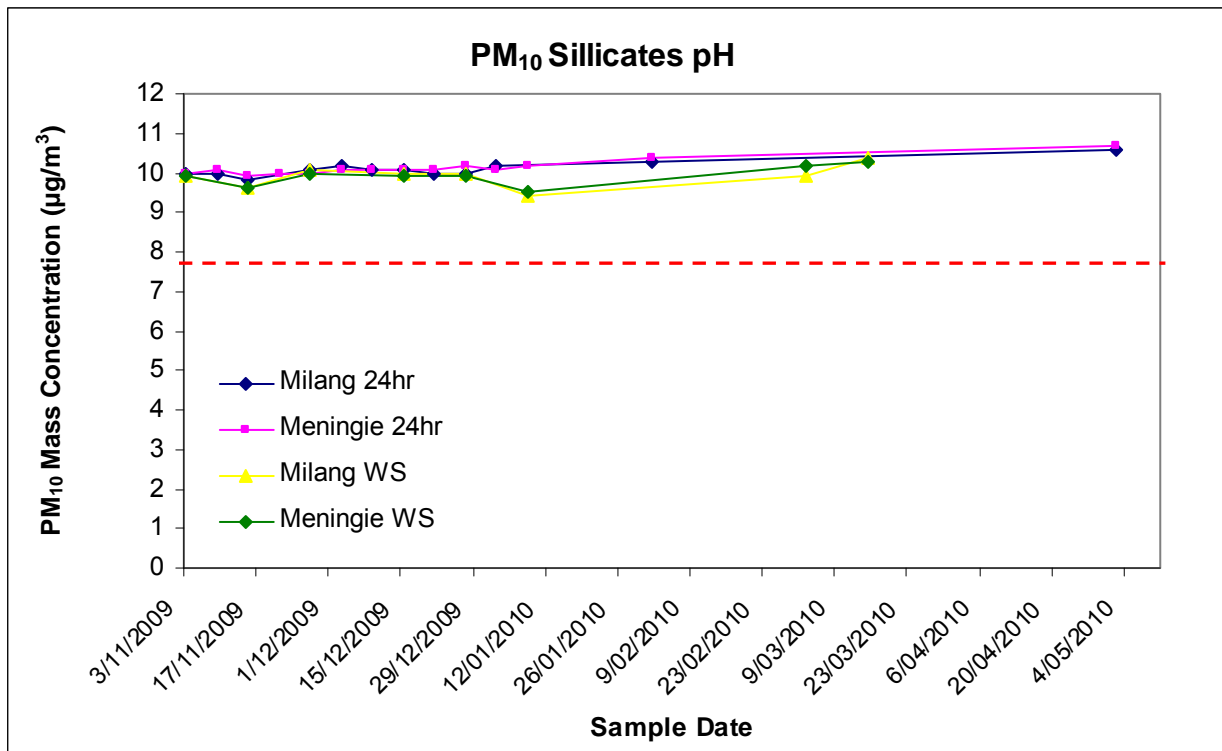


Figure 7 pH results, Milang and Meningie 2009–10

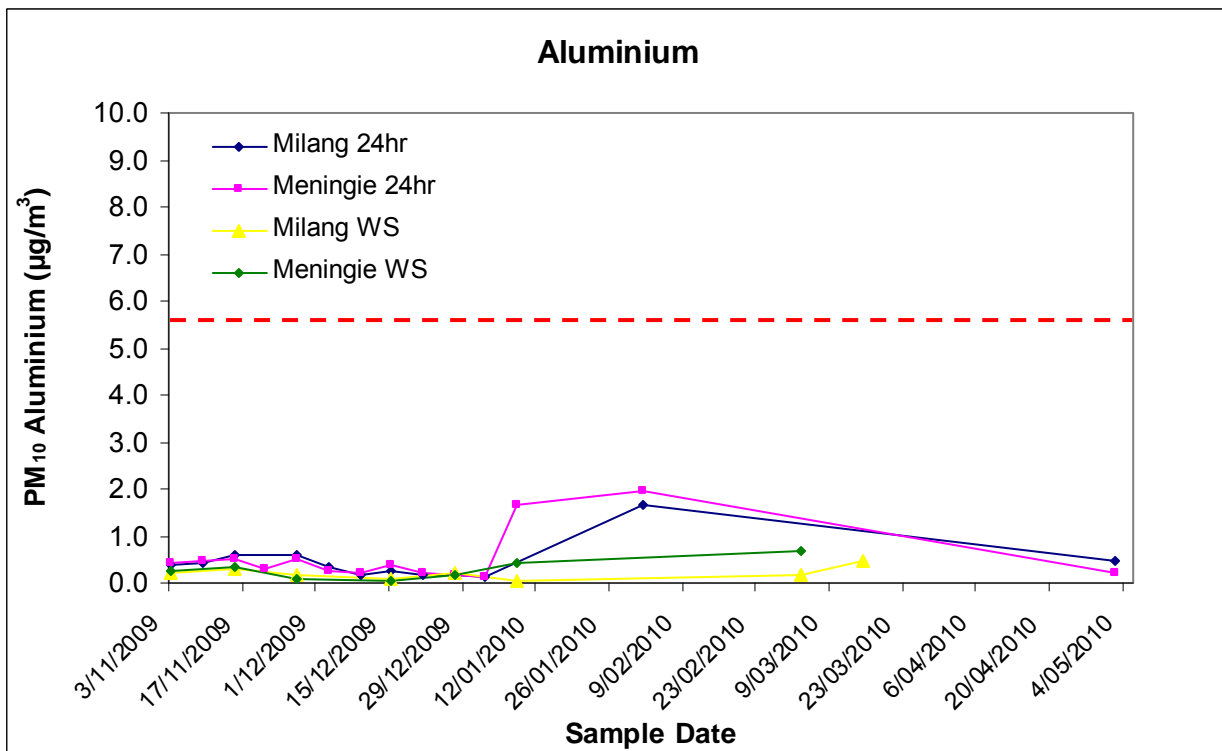


Figure 8 Aluminium results, Milang and Meningie 2009–10

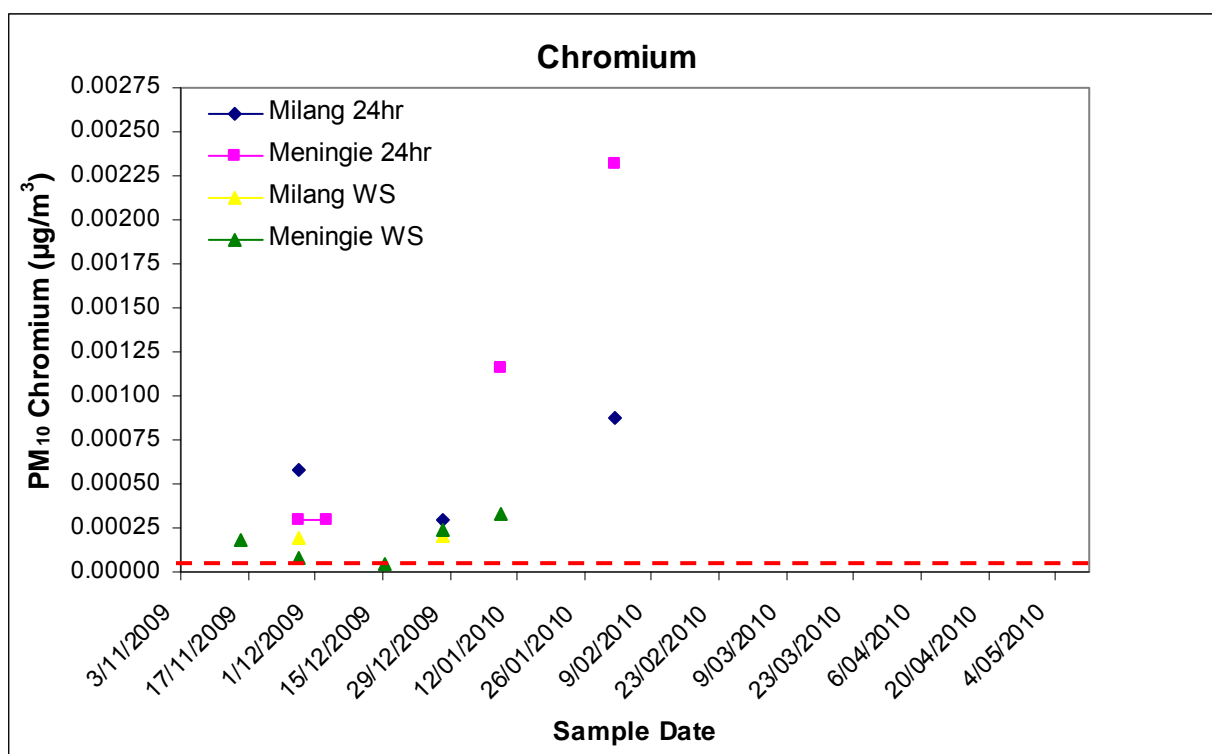


Figure 9 Chromium results, Milang and Meningie 2009–10

Table 2 Archival soil speciation of chromium in the region of Milang and Meningie

Filter No. ID	(Wet-weight Basis)	
	Total Extractable Chromium (VI) (µg/g)	Total Recoverable Chromium (µg/g)
CE107-5	0.01	1.6
CE107-6	0.01	0.4
CE107-7	0.01	3.8
CE107-8	<0.01	1.3
CE107-9	<0.01	1.3
CE107-10	<0.01	1.1
CE107-11	<0.01	0.9
CE107-12	0.01	1.5
CE107-13	0.01	0.5
CE107-14	<0.01	1.2
CE107-15	<0.01	1.2
CE107-16	<0.01	0.8
LOD (3σ)	0.01	0.5

Source: Amended from CSIRO 2010a

CSIRO mineralogy results from the Stage 3 dust sampling at Milang and Meningie also confirmed low levels of acid sulfate minerals (Table 3). Seven of the eight filters analysed indicate halite (NaCl, salt) as the dominant mineral present on the filters. The remaining filter (EE0047) shows quartz (SiO₂, sand) and halite as the co-dominant minerals.

These findings are consistent with the dust acidity and metal results presented earlier that indicated there was not significant acid sulfate soil material present. Acid sulfate soil minerals have caused localised water acidification in the Lower Lakes during the drought but it appears they pose a lower risk in regard to air quality. This may be due to the acid sulfate soil minerals typically forming a minor component of the soil mineralogy (Fitzpatrick *et al* 2008, 2010), and that acidity and metals may have been leached from the upper soil surface layer by rainfall (Simpson *et al* 2010).

Table 3 X-ray diffraction mineralogical composition of Lower Lakes dust samples 2010

Sample ID and location	Mineralogical composition
EE0015	Halite (NaCl)–dominant; Quartz–sub-dominant; Calcite, Mica, Kaolin–minor
EE0047	Quartz, Halite–co-dominant; Calcite, Mica–sub-dominant
EE0054	Halite–dominant; Quartz, Calcite, Mica–minor
EE0061	Halite–dominant; Calcite, Mica–minor
EE0063	Halite–dominant; Calcite, Gypsum–trace
EE0068	Halite–dominant; Quartz–sub-dominant; Calcite, Mica–minor; Gypsum–trace
EE0077	Halite–dominant; Quartz, Gypsum–minor; Calcite, Mica–trace
EE0088	Halite–dominant; Quartz, Calcite–minor; Gypsum–trace

* dominant (>60%), co-dominant (sum >60%), sub-dominant (20-60%), minor (5-20%), trace (<5%)

Source: Amended from CSIRO 2010b

Comparison with Adelaide Metropolitan dust results

Dust particle monitoring conducted in the same time period in the Adelaide region resulted in 20% higher concentrations of PM₁₀ particles than the Lower Lakes sites (Table 4). There is however no metal analysis for the Adelaide metropolitan area. Despite these findings, the Lower Lakes community has undoubtedly experienced an increased dust nuisance during the drought with increased complaints to SA Health.

Table 4 Comparison of average particle PM₁₀ concentrations for 3 November 2009 to 3 May 2010 between the Lower Lakes and Metropolitan Adelaide monitoring sites

Location	Average PM ₁₀ (µg/m ³)
Lower Lakes sites	
Milang 24-hour	14.3
Milang wind switched	14.0
Meningie 24-hour	14.8
Meningie wind switched	16.8
Metropolitan Adelaide sites	
Christies Beach	17.4
Netley	19.1
Elizabeth	18.5

Rainwater sampling

The results compiled from the Stage 3 (2010) rainwater tank sampling showed no distinct changes in most measured parameters in comparison with the Stage 2 (2009) data. Nutrient and metals remained well below guideline values and in most circumstances were lower than the previous year. The lowest recording was pH 5.9 compared with 6.9 the previous year. Most sites however, remained within a range of pH 6.3 to 7.2 and there were no distinct downward trends within any specific region. The sulfate concentration ranged from 1.5 mg/L to 11.7 mg/L, compared with 2.7 mg/L to 12.6 mg/L in 2009, and which was well below the guideline value 250 mg/L (NHMRC 2004).

Results from the 2010 sampling also confirmed no distinct differences between the tanks within the immediate Lower Lakes region and the control tanks from Strathalbyn. This is again consistent with the results obtained from the sampling conducted in 2009.

As in 2009, the results from the 2010 sampling were examined by SA Health. The EPA has been advised that the results obtained from the 2010 sampling were of no concern and will not pose any implications to human health. Therefore with regard to the 2009 and 2010 results, there have been no concerning changes to the quality of the drinking water from the rainwater tanks, and no current indications of any increased risk to drinking rainwater from tanks within the Lower Lakes region due to increased dust from dry lake beds containing acid sulfate soils.

4 Conclusion

Extensive areas of sediment, known to contain acid sulfate soils with low pH values, were exposed during a severe hydrological drought in the Murray–Darling basin. An air quality study was undertaken to assess the potential health risks as a result of exposure to dust blown off the dry lake beds.

High-volume dust samplers were installed in the local communities of Goolwa, Meningie and Milang for two summers. Rainwater sampling was also undertaken from the tanks of the local community following the first substantial autumn rainfall.

CSIRO also performed additional mineralogy analyses on the dust collected on the high-volume sampler filters and chromium speciation on sediment samples. These independent and multiple lines of evidence indicated there were no human health risks arising from exposure to dust blowing off the dry lake beds.

Despite these findings of low health risk, the Lower Lakes community has likely experienced an increased dust nuisance during the drought, and it is recommended that future water management strategies should consider this issue.

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Appendix 1 Analytical data–Stage 1

Table A1.1 Meningie PM₁₀ and metals analysis results, March to May 2009

Filter ID	T-00783		T-00783 ^a		T-00786		T-00779		T--00856	
	Start run date: 13/03/09		Start run date: 13/03/09		Start run date: 31/03/09		Start run date: 15/04/09		Start run date: 04/05/09	
	End Run Date: 31/03/09		End Run Date: 31/03/09		End Run Date: 15/04/09		End Run Date: 04/05/09		End Run Date: 21/05/09	
	Run time (days): 1.097		Run time (days): 1.097		Run time (days): 0.696		Run time (days): 6.997		Run time (days): 0.968	
	Mass (ug): 32700 Total Volume (m ³): 1572.18 PM10: 20.79 ug/m ³		Mass (ug): 32700 Total Volume (m ³): 1572.18 PM10: 20.79 ug/m ³		Mass (ug): not recorded Total Volume (m ³): 1178.74 PM10: not recorded		Mass (ug): 152200 Total Volume (m ³): 9555.50 PM10: 15.93 ug/m ³		Mass (ug): 18300 Total Volume (m ³): 1506.60 PM10: 12.14 ug/m ³	
Metals	Mass (ug)	Conc. (ug/m ³)	Mass (ug)	Conc. (ug/m ³)	Mass (ug)	Conc. (ug/m ³)	Mass (ug)	Conc. (ug/m ³)	Mass (ug)	Conc. (ug/m ³)
Nickel	8	0.0051	8	0.0051	4	0.0034	16	0.0017	< 2	< 0.0013
Lead	28	0.0178	< 20	< 0.0127	24	0.0204	10	0.0010	< 10	< 0.0066
Chromium	46	0.0293	24	0.0153	44	0.0373	34	0.0036	< 8	< 0.0053
Copper	30	0.0191	28	0.0178	28	0.0238	28	0.0029	< 2	< 0.0013
Zinc	280	0.1781	< 220	< 0.1399	240	0.2036	500	0.0523	< 220	< 0.1460
Iron	1260	0.8014	680	0.4325	1080	0.9162	500	0.0523	< 240	< 0.1593
Manganese	16	0.0102	10	0.0064	18	0.0153	24	0.0025	< 6	< 0.0040
Cobalt	2	0.0013	< 4	< 0.0025	< 1	< 0.0008	< 1	< 0.0001	< 2	< 0.0013
Aluminium	42200	26.8417	21000	13.3572	38200	32.4075	< 9800	< 1.0256	< 9800	< 6.5047
Arsenic	4	0.0025	< 2	< 0.0013	6	0.0051	< 2	< 0.0002	< 2	0.0013
Vanadium	16	0.0102	6	0.0038	12	0.0102	< 6	< 0.0006	< 6	< 0.0040
pH	6.871		6.871		7.023		6.650		6.718	

Note: Metals analysis was performed by EML (Chem) Pty Ltd, NATA accreditation number 2731, using the methods described in AS2800

< Less than the minimum limit of detection using the specified method

^a Re-analysis results (due to inconsistency of the EML metals analysis results with the mass of the filter, filter T-00783 was sent for re-analysis)

Table A1.2 Goolwa PM₁₀ and metals analysis results, March to May 2009

Filter ID	T-00788		T-00788 ^a		T-00787		T-00780		T-00855	
	Start run date: 13/03/09		Start run date: 13/03/09		Start run date: 31/03/09		Start run date: 16/04/09		Start run date: 04/05/09	
	End Run Date: 31/03/09		End Run Date: 31/03/09		End Run Date: 14/04/09		End Run Date: 04/05/09		End Run Date: 20/05/09	
	Run time (days): 3.128		Run time (days): 3.128		Run time (days): 3.535		Run time (days): 1.494		Run time (days): 1.904	
	Mass (ug): 134200		Mass (ug): 134200		Mass (ug): not recorded		Mass (ug): 37500		Mass (ug): 35800	
	Total Volume (m³): 4970.36		Total Volume (m³): 4970.36		Total Volume (m³): 4983.11		Total Volume (m³): 2308.00		Total Volume (m³): 2977.60	
	PM10: 27.00 ug/m ³		PM10: 27.00 ug/m ³		PM10: not recorded		PM10: 16.25 ug/m ³		PM10: 12.02 ug/m ³	
Metals	Mass (ug)	Conc. (ug/m ³)	Mass (ug)	Conc. (ug/m ³)	Mass (ug)	Conc. (ug/m ³)	Mass (ug)	Conc. (ug/m ³)	Mass (ug)	Conc. (ug/m ³)
Nickel	14	0.0028	12	0.0024	16	0.0032	2	0.0009	< 2	< 0.0007
Lead	26	0.0052	< 20	< 0.0040	22	0.0044	< 5	< 0.0022	<10	< 0.0034
Chromium	58	0.0117	36	0.0072	64	0.0128	10	0.0043	< 8	< 0.0027
Copper	24	0.0048	24	0.0048	24	0.0048	22	0.0095	< 2	< 0.0007
Zinc	260	0.0523	220	0.0443	260	0.0522	< 220	< 0.0953	< 220	< 0.0739
Iron	1280	0.2575	720	0.1449	1200	0.2408	< 240	< 0.1040	< 240	< 0.0806
Manganese	14	0.0028	10	0.0020	18	0.0036	< 6	< 0.0026	< 6	< 0.0020
Cobalt	< 1	<0.0002	< 4	< 0.0008	< 1	< 0.0002	< 1	< 0.0004	< 2	< 0.0007
Aluminium	40200	8.0879	20200	4.0641	38200	7.6659	< 9800	< 4.2461	< 9800	< 3.2912
Arsenic	4	0.0008	< 2	< 0.0004	4	0.0008	< 2	< 0.0009	< 2	< 0.0007
Vanadium	14	0.0028	6	0.0012	12	0.0024	< 6	< 0.0026	< 6	< 0.0020
pH	6.556		6.556		6.591		6.736		6.606	

Note: Metals analysis was performed by EML (Chem) Pty Ltd, NATA accreditation number 2731, using the methods described in AS2800

< Less than the minimum limit of detection using the specified method

^a Re-analysis results (due to inconsistency of the EML metals analysis results with the mass of the filter, filter T-00788 was sent for re-analysis)

Appendix 2 Health reference values for metals in air

Table A2.1 Reference values for metals in air

	Reference Value		Source	Reference Value		Source	Comments
	$\mu\text{g}/\text{m}^3$	Name		mg/m^3	Name		
Ag	0.24	RV	Derived	0.01	TWA	ASCC	Soluble compounds
Al	5.2	PRG	US EPA (2009)				
As	0.0007	GAQ	WHO (2000)				1.0×10^{-6} risk
Cd	0.3	GAQ	WHO (2000)				
Co	1.2	RV	Derived	0.05	TWA	ASCC	Metal dust & fumes (as Co)
Cr	0.000025	GAQ	WHO (2000)				
Cu	23.8	RV	Derived	1	TWA	ASCC	Dusts & mists (as Cu)
Mn	0.15	GAQ	WHO (2000)				
Ni	0.0025	RV	WHO (2000)				1.0×10^{-6} risk
Pb	0.5		NEPC (1998)				Standards & Goals
Sb	0.21	PRG	US EPA (2009)				
Se	4.8	RV	Derived	0.2	TWA	ASCC	
V	1.0	GAQ	WHO (2000)				
Zn	23.8	RV	Derived	1	TWA	ASCC	Zinc chloride (fume)
Zn	0.024	RV	Derived	0.001	TWA	ASCC	Zinc chromate (as Cr)
Zn	238.1	RV	Derived	10	TWA	ASCC	Zinc oxide (dust)

RV: Reference Value; GAQ: Guidelines for Air Quality; ASCC: ASCC (1995); TWA: Time Weighted Average

Source: Golder Associates 2008

Appendix 3 Analytical data–Stage 3

Table A3.1 Milang 24-hour samples of PM₁₀

Sampling Date	PM ₁₀	Al	As	Cd	Cr	Co	Cu	Fe	Pb	Mn	Ni	V	Zn	pH to AS128
	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	
3/11/2009	13.4	0.38	<LDL	<LDL	<LDL	<LDL	<LDL	0.05	<LDL	0.00	<LDL	<LDL	<LDL	10
9/11/2009	16.5	0.43	<LDL	<LDL	<LDL	<LDL	<LDL	0.28	<LDL	0.01	<LDL	<LDL	<LDL	10
15/11/2009	26.5	0.61	<LDL	<LDL	<LDL	<LDL	<LDL	0.37	<LDL	0.01	N/A	0.00	<LDL	9.8
21/11/2009														
27/11/2009	16.2	0.61	<LDL	<LDL	0.00	<LDL	<LDL	0.40	<LDL	0.01	0.00	0.00	0.14	10.1
3/12/2009	16.5	0.35	<LDL	<LDL	<LDL	<LDL	<LDL	0.09	<LDL	0.00	<LDL	<LDL	0.28	10.2
9/12/2009	7.3	0.17	<LDL	<LDL	<LDL	<LDL	<LDL	0.06	<LDL	0.00	<LDL	<LDL	0.09	10.1
15/12/2009	15.5	0.26	<LDL	<LDL	<LDL	<LDL	<LDL	0.20	<LDL	0.00	<LDL	<LDL	0.05	10.1
21/12/2009	14.5	0.17	<LDL	<LDL	<LDL	<LDL	<LDL	0.05	<LDL	0.00	<LDL	<LDL	0.09	10
27/12/2009	10.6	0.17	<LDL	<LDL	0.00	<LDL	<LDL	0.07	<LDL	0.00	<LDL	<LDL	0.07	10
2/01/2010	14.4	0.15	<LDL	<LDL	<LDL	<LDL	<LDL	0.05	<LDL	0.00	<LDL	<LDL	0.07	10.2
8/01/2010	19.7													
14/01/2010	7.8													
20/01/2010	10.7													
26/01/2010	11.4													
1/02/2010	27.7	1.65	<LDL	<LDL	0.00	<LDL	<LDL	0.12	<LDL	0.00	<LDL	<LDL	0.30	10.3
7/02/2010	17.4													
13/02/2010	16.2													
19/02/2010	18.0													
25/02/2010	13.5													
3/03/2010	18.3													
9/03/2010	13.0													
15/03/2010	13.2													
21/03/2010	12.0													
27/03/2010	13.6													
2/04/2010	14.3													
8/04/2010	8.4													
14/04/2010	7.4													
20/04/2010	8.2													
26/04/2010	9.8													
2/05/2010	17.7	0.49	<LDL	<LDL	<LDL	<LDL	<LDL	0.04	<LDL	<LDL	<LDL	<LDL	0.02	10.6

Table A3.2 Milang wind switched samples of PM₁₀

Sampling Date	PM10	Al	As	Cd	Cr	Co	Cu	Fe	Pb	Mn	Ni	V	Zn	pH to AS128
	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	
3/11/2009	12.7	0.23	<LDL	<LDL	<LDL	<LDL	<LDL	0.16	<LDL	0.00	<LDL	<LDL	<LDL	9.9
15/11/2009	18.7	0.28	<LDL	<LDL	<LDL	<LDL	<LDL	0.20	<LDL	0.00	0.00	0.00	<LDL	9.6
27/11/2009	13.8	0.17	<LDL	<LDL	0.00	<LDL	<LDL	0.04	<LDL	0.00	0.00	<LDL	0.09	10.1
15/12/2009	7.7	0.08	<LDL	<LDL	<LDL	<LDL	<LDL	0.02	<LDL	0.00	<LDL	<LDL	0.03	10
27/12/2009	17.5	0.20	<LDL	<LDL	0.00	<LDL	<LDL	0.03	<LDL	0.00	<LDL	<LDL	0.09	10
8/01/2010	13.3	0.04	<LDL	<LDL	<LDL	<LDL	<LDL	0.05	<LDL	0.00	<LDL	0.00	0.01	9.4
20/01/2010	11.3													
1/02/2010	13.3													
13/02/2010	17.5													
3/03/2010	21.6	0.19	<LDL	<LDL	0.00	<LDL	<LDL	0.21	<LDL	0.00	0.00	0.00	<LDL	9.9
15/03/2010	21.6	0.48	<LDL	<LDL	<LDL	<LDL	<LDL	0.22	<LDL	0.00	<LDL	0.00	0.01	10.4
27/03/2010	12.7													
8/04/2010	11.5													
20/04/2010	8.2													
2/05/2010	8.7													

Table A3.3 Meningie 24-hour samples of PM₁₀

Sampling date	PM ₁₀	Al	As	Cd	Cr	Co	Cu	Fe	Pb	Mn	Ni	V	Zn	pH to AS128
	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	
3/11/2009	13.9	0.43	<LDL	<LDL	<LDL	<LDL	<LDL	0.04	<LDL	0.00	<LDL	<LDL	<LDL	10
9/11/2009	15.8	0.46	<LDL	<LDL	<LDL	<LDL	<LDL	0.37	<LDL	0.01	<LDL	<LDL	<LDL	10.1
15/11/2009	22.7	0.52	<LDL	<LDL	<LDL	<LDL	<LDL	0.37	<LDL	0.01	<LDL	0.00	<LDL	9.9
21/11/2009	14.3	0.29	<LDL	<LDL	<LDL	<LDL	<LDL	0.05	<LDL	0.00	<LDL	<LDL	<LDL	10
27/11/2009	15.4	0.49	<LDL	<LDL	0.00	<LDL	0.01	0.31	0.00	0.01	0.00	<LDL	0.11	10
3/12/2009	16.7	0.26	<LDL	<LDL	0.00	<LDL	<LDL	0.14	<LDL	0.00	<LDL	<LDL	0.12	10.1
9/12/2009	9.0	0.23	<LDL	<LDL	<LDL	<LDL	<LDL	0.05	<LDL	0.00	<LDL	<LDL	0.08	10.1
15/12/2009	15.2	0.38	<LDL	<LDL	0.01	<LDL	<LDL	0.19	<LDL	0.00	<LDL	<LDL	0.19	10.1
21/12/2009	11.7	0.23	<LDL	<LDL	<LDL	<LDL	<LDL	0.16	<LDL	0.00	0.00	0.00	0.08	10.1
27/12/2009	9.2	0.17	<LDL	<LDL	<LDL	<LDL	<LDL	0.08	<LDL	0.00	<LDL	<LDL	0.08	10.2
2/01/2010	16.0	0.14	<LDL	<LDL	<LDL	<LDL	<LDL	0.10	<LDL	0.00	<LDL	<LDL	0.08	10.1
8/01/2010	22.3	1.65	<LDL	<LDL	0.00	<LDL	<LDL	0.62	<LDL	0.01	<LDL	0.00	0.27	10.2
14/01/2010	10.6													
20/01/2010	10.1													
26/01/2010	17.7													
1/02/2010	31.5	1.94	<LDL	<LDL	0.00	<LDL	<LDL	0.30	0.01	0.01	<LDL	0.00	0.30	10.4
7/02/2010	14.4													
13/02/2010	12.5													
19/02/2010	18.5													
25/02/2010	14.4													
3/03/2010	18.4													
9/03/2010	14.5													
15/03/2010	9.4													
21/03/2010	16.6													
27/03/2010	12.5													
2/04/2010	14.3													
8/04/2010	11.0													
14/04/2010	9.5													
20/04/2010	11.3													
26/04/2010	8.5													
2/05/2010	19.9	0.20	<LDL	<LDL	<LDL	<LDL	<LDL	0.07	<LDL	<LDL	<LDL	<LDL	0.01	10.7

Table A3.4 Meningie wind switched samples of PM₁₀

Sampling date	PM10	Al	As	Cd	Cr	Co	Cu	Fe	Pb	Mn	Ni	V	Zn	pH to AS128
	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	
3/11/2009	13.2	0.25	<LDL	<LDL	<LDL	<LDL	<LDL	0.17	<LDL	0.00	<LDL	<LDL	<LDL	9.9
15/11/2009	21.2	0.34	<LDL	<LDL	0.00	<LDL	<LDL	0.35	0.00	0.01	0.00	0.00	<LDL	9.6
27/11/2009	11.9	0.09	<LDL	<LDL	0.00	<LDL	<LDL	0.05	<LDL	0.00	0.00	<LDL	0.05	10
15/12/2009	9.7	0.05	<LDL	<LDL	0.00	<LDL	<LDL	0.04	<LDL	0.00	0.00	0.00	0.02	9.9
27/12/2009	13.7	0.15	<LDL	<LDL	0.00	<LDL	<LDL	0.11	<LDL	0.00	0.00	0.00	0.06	9.9
8/01/2010	19.8	0.41	<LDL	<LDL	0.00	<LDL	<LDL	0.39	0.00	0.01	0.00	0.00	0.03	9.5
20/01/2010	17.4													
1/02/2010	19.6													
13/02/2010	18.1													
3/03/2010	22.0	0.69	<LDL	<LDL	<LDL	<LDL	<LDL	0.30	<LDL	0.01	0.00	0.00	0.08	10.2
15/03/2010	31.6	9.16	<LDL	<LDL	0.00	<LDL	<LDL	0.60	<LDL	0.01	0.00	<LDL	0.27	10.3
27/03/2010	12.1													
8/04/2010	12.5													
20/04/2010	9.2													
2/05/2010	9.9													

* The Meningie sample dated 15/3/2010 had a very low sample volume (equivalent to <5% of other samples) thus not providing for an accurate measurement to be made.

Table A3.5 Lower detectable limits for metals

Aluminium (Al)	Arsenic (As)	Cadmium (Cd)	Chromium (Cr)	Cobalt (Co)	Copper (Cu)	Iron (Fe)	Lead (Pb)	Manganese (Mn)	Nickel (Ni)	Vanadium (V)	Zinc (Zn)
µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³	µg/m ³
0.012	0.012	0.001	0.001	0.001	0.009	0.001	0.003	0.000	0.001	0.001	0.001

Notes: Missing, invalid or no data are represented by blanks
Metal concentrations are background corrected
<LDL means less than detectable limits

days when metals were analysed