

LEGISLATIVE COUNCIL

876

QUESTION WITHOUT NOTICE (Of which some notice has been given)

Tuesday, 6 November 2012

Hon Robin Chapple to the Minister for Mental Health representing the Minister for Environment.

With reference to the articles contained in the Sunday Times of 04/11/2012 in respect of comments made in a letter referenced CE01314/09 by Keiran McNamara the Director General of the Department of Environment and Conservation in respect of the *Environmental Protection (Goldfields Residential Areas) (Sulfur Dioxide) Policy 2003 (EPP)* and ask:

1. Why are the levels of SO₂ and Hg (Mercury) from Kalgoorlie Consolidated Gold Mines allowed when these emissions would not be allowed in most other Australian States, or other developed countries, where principles such as Australian/international best practice, best available technology, or similar, are applied?
2. What is the Minister doing to support Keiran McNamara the Director General of the Department of Environment and Conservation in the imposition of flue gas desulfurisation (FGD) or to require significant legislative change by adopting the approach taken by New South Wales and Victoria to strictly limit the Design Ground Level Concentrations (DGLCs) at the boundary of each emitting premises?
3. What is the Minister doing to ensure that any exceedance of the EPP limit will result in a successful prosecution given the difficulties of such prosecutions identified by the Director General?

I thank the Hon. Member for some notice of this question.

1. The extract quoted in *The Sunday Times* on 4 November 2012 was from the Department of Environment and Conservation's (DEC) submission dated 15 February 2010 to the Environmental Protection Authority (EPA) in relation to the Review of the *Environmental Protection (Goldfields Residential Areas) (Sulfur Dioxide) Policy 2003 (EPP)*.

The quoted extract needs to be read in the context of the immediately following sentence, which stated: "If the production of sulfuric acid from the SO₂ generated is not currently an economically viable option, or if the disposal of sulfuric acid so generated represents a greater environmental risk than the stack emission of SO₂ to the atmosphere, then these reasons may form a cogent argument for continuation of the current emission to atmosphere".

2. DEC's comments were an input to the EPA review of the EPP and the Minister for Environment is guided by the EPA's recommendations to him on such matters.
3. The EPP sets a sulfur dioxide standard and limit. Industry licences adopt the limit and provide a regulatory mechanism for the enforcement of that limit. Enforcement action in respect of licence conditions is a matter for DEC in accordance with its *Enforcement and Prosecution Policy 2008*.





Government of Western Australia
 Department of Environment and Conservation

Your ref: D102624
 Our ref: CEO1314/09
 Enquiries: Theo Bazen
 Phone: [REDACTED]
 Fax:
 Email:

[REDACTED]
 Deputy Chairman
 Environmental Protection Authority
 Locked Bag 33
 Cloisters Square
 PERTH WA 6850

Opened by Department of Environment
 & Conservation Corporate Information
 Services Atrium
 16 FEB 2010
 For the Office of the Environmental
 Protection Authority

Dear [REDACTED]

**DISCUSSION PAPER – REVIEW OF THE ENVIRONMENTAL PROTECTION
 (GOLDFIELDS RESIDENTIAL AREAS) (SULFUR DIOXIDE) POLICY 2003**

I refer to your letter of 11 December 2009 inviting comment from the Department of Environment and Conservation (DEC) on the Review of the *Environmental Protection (Goldfields Residential Areas) (Sulfur Dioxide) Policy 2003 (EPP)*.

DEC is pleased to enclose its submission and appreciates the opportunity to provide comment on the review of the EPP.

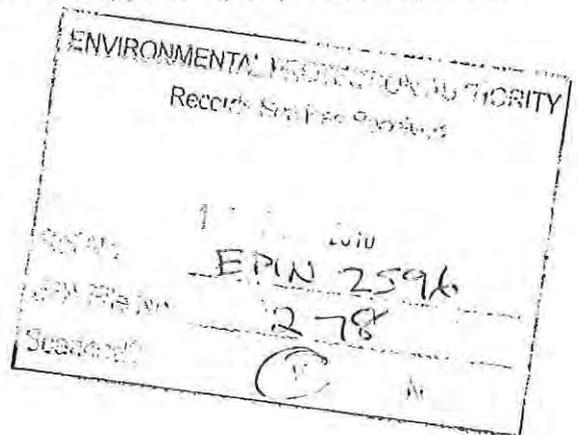
Yours sincerely

[REDACTED]

Keiran McNamara
 DIRECTOR GENERAL

15 February 2010

Att



DIRECTOR GENERAL AND ENVIRONMENTAL SERVICES DIVISIONS: The Atrium, 168 St Georges Terrace, Perth, Western Australia 6000
 Phone: (08) 6467 5000 Fax: (08) 6467 5562 TTY: 1880 555 630

PARKS AND CONSERVATION SERVICES DIVISIONS: Executive: Corner of Australia II Drive and Hackett Drive, Crawley, Western Australia 6009
 Phone: (08) 9442 0300 Fax: (08) 9386 1578 Operations: 17 Dick Perry Avenue, Technology Park, Kensington, Western Australia 6151
 Phone: (08) 9219 8000 Fax: (08) 9334 0498 TTY: 9334 0546

POSTAL ADDRESS FOR ALL DIVISIONS: Locked Bag 104, Bentley Delivery Centre, Western Australia 6983
 www.dec.wa.gov.au
 wa.gov.au

**DISCUSSION PAPER – REVIEW OF THE ENVIRONMENTAL PROTECTION
(GOLDFIELDS RESIDENTIAL AREAS) (SULFUR DIOXIDE) POLICY 2003**

Submission by:

DEPARTMENT OF ENVIRONMENT AND CONSERVATION

February 2010

The Department of Environment and Conservation (DEC) has reviewed the discussion paper and provides the following comments.

The Goldfields Region of DEC includes the areas defined by the *Environmental Protection (Goldfields Residential Area Sulfur Dioxide) Policy 2003* (EPP). DEC's Goldfields Regional Office issues licences under the *Environmental Protection Act 1986* to industries in this region, including those industries which emit sulfur dioxide (SO₂).

The EPP has generally provided a sound basis for imposing licence conditions for SO₂ emissions for those industries. This has led to an improvement in the air quality for communities in the areas defined by the EPP, and has enhanced community confidence in DEC's regulatory capacity.

However, there has been a significant increase in the number of complaints to DEC regarding SO₂ impacts outside the EPP defined areas. These complaints are further supported by field monitoring results, which indicate increased levels of SO₂ in areas where people travel (such as the Goldfields Highway) and where people work in close proximity to premises which emit SO₂.

To improve air quality in the Goldfields region, DEC recommends that the area covered by the EPP be increased, as outlined in yellow on the map at Attachment 1. This would retain the areas originally defined in the EPP for maximum protection of human health. The remaining area could have a higher allowable SO₂ level (to be set in consultation with the Department of Health), which still protects human health and the environment. It would protect people passing through the area, or working within the immediate area of influence of any major industry which emits SO₂. It would also accommodate the SO₂ control that industries emitting SO₂ can reasonably achieve.

An exclusion buffer zone (in the order of one kilometre radius around each major industry which emits SO₂) could be considered to ensure adequate physical separation between those industries and both the general community and neighbouring activities. The purpose of such a buffer zone would be to provide a margin of protection to the community from any serious stack downwash scenarios that may raise the ground level concentrations of SO₂ to undesirable levels.

DEC recommends that the EPP is retained, and not significantly altered or removed, until there is a proven and viable alternative management regime for SO₂ emissions in place for the region. If the EPP is removed, the next standard SO₂ level available for the maintenance of air quality is the National Environment Protection Council's *Ambient Air Quality - National Environment Protection Measure* (NEPM), which targets inhabited areas but not necessarily the wider environment.

Another option, but one which would require significant legislative change, is to adopt the approach taken by New South Wales and Victoria to strictly limit the Design Ground Level Concentrations (DGLCs) at the boundary of each emitting premises.

However, the economic feasibility and corresponding timeframe for achievement of this proposal would need to be considered.

SO₂ Emission Limits

The total mass emissions of SO₂ and Hg (Mercury) from Kalgoorlie Consolidated Gold Mines' facilities are very high in volume. These emissions would not be allowed in most other Australian States, or other developed countries, where principles such as Australian/international best practice, best available technology, or similar, are applied. If the production of sulfuric acid from the SO₂ generated is not currently an economically viable option, or if the disposal of sulfuric acid so generated represents a greater environmental risk than the stack emission of SO₂ to atmosphere, then these reasons may form a cogent argument for continuation of the current emission to atmosphere.

DEC recommends that, in the case of continued emission of SO₂ to atmosphere, the EPP incorporates ongoing reduction of SO₂ emissions to atmosphere through the imposition of flue gas desulfurisation (FGD), in economically achievable stages over a number of years. This is considered particularly relevant in view of the recently extended life of Kalgoorlie mining operations (the "Super Pit"), which will continue to feed the SO₂ emitters.

Difficulties with enforcement of the EPP

Currently, unless an SO₂ emitter acknowledges responsibility for any exceedance of the EPP limit, a successful prosecution may be more difficult than other approaches for the following reasons:

- Such exceedances are most likely to occur under complicated meteorological conditions, which are the very conditions that prevent DEC being able to convince a court (beyond reasonable doubt) about the exact source of the emissions. It should be noted that licensing, based on ambient concentrations set out in the EPP, is unique and based on historical approaches. DEC considers that a better method is to control emissions at the source (ie. stack concentrations) as the most scientifically defensible (and legally robust) manner of ensuring environmental regulation and compliance with licence conditions.
- Lack of deeming provisions for ambient monitors and meteorological monitoring equipment greatly complicates the task of presenting robust and defensible data in court. Again, there have been difficulties in achieving this due to the historical siting of stations that prevent meteorological monitoring equipment from meeting relevant Australian guidelines (such as proximity to large buildings, etc) and the costs of moving to and implementing a more ideal solution.

Response to specific questions in the EPP Discussion Paper

Should industry have a limit on the amount of emissions that they can emit in addition to the current controls that protect the residential areas?

Please refer to comments above in relation to SO₂ emission limits, and the need to use best practice, best available technology, etc. There is currently a cap on licence fees, therefore it would not be inconsistent to impose a similar cap on SO₂ and mercury.

Is vegetation adequately protected outside the protected residential areas? If not, how should this be managed and why?

The Kalgoorlie Air Monitoring Network (KAMN) undertakes vegetation monitoring and reporting for the three ore roasters, which currently generate the SO₂ emissions, in accordance with practices prevalent at the time of commissioning these roasters, DEC considers that sufficient data have now been collected to determine any adverse impacts on vegetation. In October 2009, DEC requested that KAMN collate all such monitoring data and have it assessed by a qualified, independent third party. While KAMN appreciated the merit of such a compilation, it did not consider it a priority and no commitment was given to provide it.

DEC recognises that, compared to the clearing of vegetation for mining and other processes affecting vegetation (such as altered fire regimes and overgrazing), the relative impact of SO₂ is likely to be minimal. However, DEC considers it prudent to ensure the long-term health of the vegetation by continued vegetation monitoring by the major SO₂ emitters, and a study of the vegetation monitoring data collected to date by KAMN for any adverse impacts.

Are there any animals or plants that you are concerned about that may be negatively affected by the SO₂ emissions?

Since native fauna (and pastoral livestock) are heavily reliant on the natural vegetation, DEC considers a sound knowledge of the state of vegetation health is central to ensuring fauna health and probably more useful than any specific fauna monitoring program.

Should other substances in addition to SO₂ be included in the EPP (e.g. mercury)? If so what and why?

Mercury is identified as an issue in the Goldfields region, however, DEC does not recommend management of mercury through the EPP for the following reasons:

- 1) investigations indicate approximately 90 per cent of the mercury is produced from one industry source; and
- 2) mercury emissions are not amenable to control via ambient measurement in the same manner as SO₂ (which can be continuously measured with short averaging times). DEC considers mercury would be best controlled through the use of emission limits.

Further information on the presence and impacts of mercury air pollution in Australia can be found in the Clean Air Society of Australia and New Zealand (CASANZ) conference paper *Modelling The emission and Transport of Mercury in Australia* by Dr Martin Cope et al. A copy of the paper is at Attachment 2.

Should industry continue to monitor the SO₂ ambient concentrations in the Goldfields? Is the current monitoring programme adequate? Should more sites be monitored?

DEC considers the monitoring program should be maintained in the Goldfields, and that the program is adequate in its present form for the current policy areas. No further monitoring stations are needed in these areas. Comment is made below regarding other areas.

Would you like to see the air quality outside of the residential areas be managed? If so where and why?

DEC recommends that there be a re-evaluation of the presence of communities and other "sensitive receptors" present in the Goldfields region which are not currently protected by the EPP. An example of this is the major highways in the Goldfields region, which preliminary research (section 5.1 of the discussion paper) indicates are being impacted by high levels of SO₂ produced from the Gidji Roaster. These roads need to be considered as additional areas to protect in a revised EPP for the Goldfields and continuous monitoring may be required.

Do you think that air quality in the Goldfields region still requires an EPP or similar tool for its management?

DEC considers the EPP is still required for air quality management in the Goldfields region. Industries can cause high concentrations of SO₂ where people live, work or travel in the region, and this warrants the ongoing management of air quality through an EPP. Despite some difficulties with enforcement of the EPP, it ensures that industries take the emission of SO₂ in residential areas seriously.

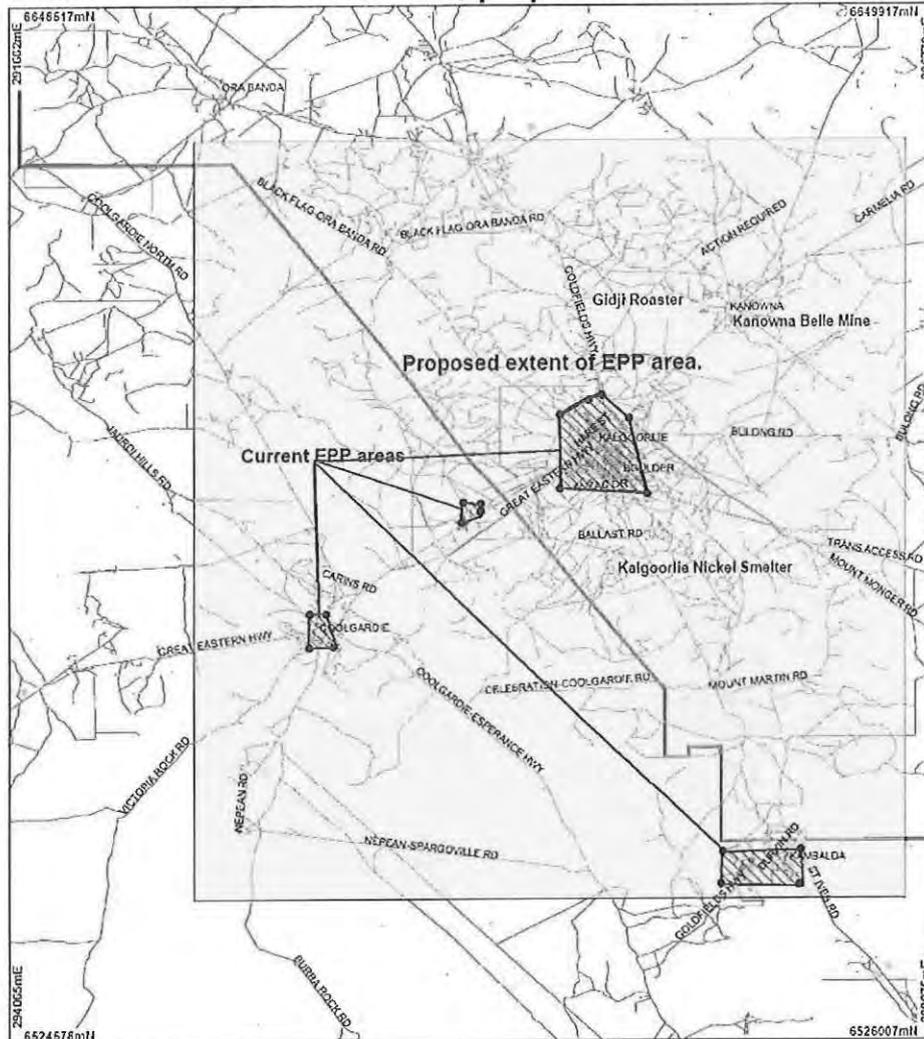
In particular, the current monitoring framework has proved successful in this regard. Until there is a proven alternative management regime for SO₂ emissions in place in the Goldfields, DEC recommends that the EPP is maintained as it provides a single coherent policy that enables effective environmental regulation. Achieving equivalent effectiveness under other provisions of the Environmental Protection Act alone is considered problematic.

What would you think if the Goldfields EPP was removed and another government instrument (e.g. Industry Licensing) was used to protect the Goldfields airshed?

DEC foresees a significant workload to achieve the same effectiveness of the EPP through other provisions of the Environmental Protection Act such as licensing under Part V. The EPP forces uniformity in licensing that can otherwise easily be eroded with time if the EPP was to be removed, as disparities may arise in licences which are renewed at different times.

Notwithstanding these administrative issues, as stated above, licensing would be reliant upon stack emission limits for individual industries which would introduce a more stringent management regime on industries, in that the flexibility that is available to operators in complying with ambient limits within the EPP area would not be available if limits were set on stacks.

DRAFT - Goldfields proposed EPP area



LEGEND

- | | | |
|----------------------------|------------------|-----------------------|
| Local Government Authority | A | Kalbarra |
| Road Centreline | B | Fell Point |
| Town | C | NPI, Point Facilities |
| Geographic Bound line | EPP Areas | |

N

0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200

Scale 1:67559
 (As per the map scale of 1:67559)
 Geospatial Data Australia 1994
 Note: The data in this map has not been
 checked for accuracy. This may result in
 distortion or measurement inaccuracies.

Prepared by Flora Westcott
 Prepared for CEO 13/05/05
 Date: 12/01/05 1:29:46 PM

Information on this map should be
 confirmed with the data custodian and checked
 by the appropriate authority.



COPY

MODELLING THE EMISSION AND TRANSPORT OF MERCURY IN AUSTRALIA

Cope, Martin¹, Lee, Sunhee¹, Hibberd, Mark¹, Meyer, Mick¹, McGregor, John¹, Nelson, Peter², Morrison, Anthony², Malfroy, Hugh³.

¹ Centre for Climate and Weather Research, Principal Private Bag No. 1, Aspendale, Vic., 3195, Australia

² Graduate School of the Environment, Macquarie University, NSW, 2109, Australia
³ Malfroy Environmental Strategies, 16/37 Nicholson St, E. Balmain, NSW, 2041, Australia

This paper describes the development and application of a multi-scale atmospheric mercury modelling system for the Australian region. This task is one component of a study (funded by the Department of Environment, Water, Heritage and Arts) that has been undertaken by a team from Macquarie University and the CSIRO into the Transport and Fate of Mercury Sources in Australia.

The modelling system considers the emissions of mercury speciated into elemental gaseous, reactive gaseous and particulate mercury) from anthropogenic sources including large industrial complexes, commercial-domestic sources and motor vehicles, and from natural sources such as vegetation, soils, water and fires. A companion paper (Nelson et al. 2009) gives a description of the emissions inventory development process. The emission, transport and loss through wet and dry deposition of the three mercury species has been modelled at the continental scale (horizontal grid spacing of 25 km); at the urban scale (for Melbourne and Sydney- 3 km grid spacing) and at the local scale (for a selection of large industrial sources- 1 km spacing).

Keywords: mercury, emissions, atmospheric transport, deposition, concentration, modelling, Australia.

1. Introduction

Mercury is a persistent pollutant which is present throughout the earth's biosphere. Mercury can exist in many forms, but of particular concern to the environment is methylmercury which bioaccumulates and can be ingested by animals and humans through the consumption of fish and shell fish. Methylmercury is known to lead to impaired neurological development in fetuses, infants and children

(<http://www.epa.gov/hg/effects.htm>).

Mercury is a naturally occurring element which is present in rocks and ores and may be released naturally through volcanic eruptions, the weathering of rocks and from undersea vents

(<http://www.ec.gc.ca/MERCURY/SM/EN/sm-ns.cfm>). Anthropogenic processes such as non-ferrous metal production, coal combustion and waste incineration also emit mercury as a by-product. Additionally, mercury is re-emitted from surface deposits formed from the transport and deposition of mercury present in the atmosphere.

Atmospheric mercury primarily exists as elemental mercury vapour Hg^0 . Being relatively insoluble, Hg^0 has a global residence time of about 0.5–2 years in the atmosphere and thus is available to be transported over long distances (Lin et al., 2006). Atmospheric mercury also exists in a gaseous divalent form (reactive gaseous mercury; RGM) and in particulate form (HgP). RGM is highly soluble in water and thus is readily deposited to the

surface by wet and dry deposition. Particulate mercury, which exists mainly in the fine particle size fraction ($<PM_{2.5}$), is predominantly lost through cloud water scavenging and wet deposition.

Following an extensive overview of the current knowledge of mercury sources and environmental impacts, the United Nations Environment Programme's (UNEP) Governing Council concluded that there is sufficient evidence of significant global adverse impacts from mercury to warrant further action. At the national level, this should include actions to identify populations at risk and to reduce human generated releases

(<http://www.chem.unep.ch/MERCURY/Report/Final%20Assessment%20report.htm>).

In 2008 the Commonwealth Department of Environment, Water, Heritage and Arts (DEWHA) engaged a team from Macquarie University and CSIRO to undertake a study into "Mercury Sources, Transportation and Fate In Australia". The development of an inventory of atmospheric mercury emissions comprised one component of this study and is discussed in Nelson et al. (2009). In this paper, we describe how this inventory and atmospheric dispersion modelling was used to generate estimates of atmospheric mercury concentrations and deposition fluxes at three spatial scales- the Australian continent; at the urban scale- (for Melbourne and Sydney); and at the local scale- within a few kilometres of five significant point source emitters. This information forms one input into a broader environmental assessment of

mercury impacts in Australia which has been undertaken by Macquarie University.

2. Methodology

The atmospheric emission and transport modelling was undertaken at the continental scale using the system shown in Figure 1. A similar higher resolution modelling system was used to generate urban- and local-scale concentration and deposition predictions. The continental system comprises a weather simulation model, an inventory of mercury emissions from anthropogenic and natural sources and a model for simulating the atmospheric transport and its subsequent fate via wet and dry deposition.

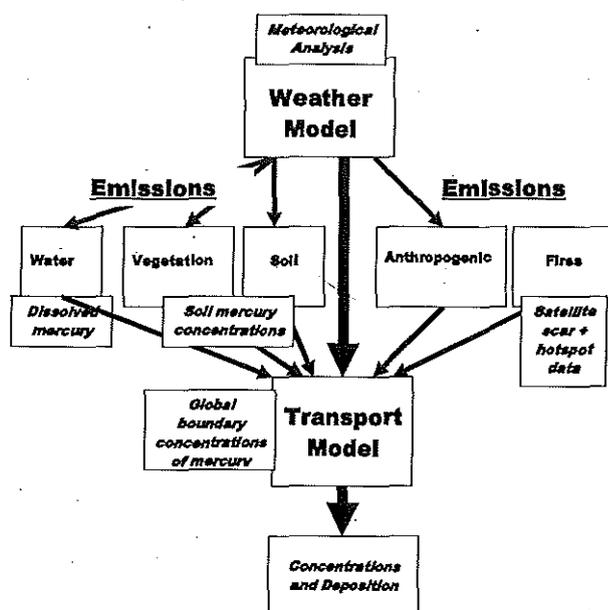


Figure 1. Schematic diagram showing the continental-scale atmospheric mercury transport modelling system.

The modelling was undertaken for Hg^0 , RGM and HgP . Although the oxidation-reduction chemistry of mercury has not been modelled at this stage, account was taken of the different solubility properties of each mercury species and the subsequent differing rates of deposition. This is illustrated in Table 1 which contrasts the significantly different surface uptake resistances and Henry's law constants for Hg^0 and RGM.

The mercury transport modelling was undertaken for 2006. This year was selected because a number of significant bushfires occurred in the southern region of Australia during this period and thus the transport modelling should provide an upper bound estimate of the contribution of mercury emissions from bushfires to the atmospheric loading of mercury in Australia.

Table 1 Representative deposition properties for Hg^0 and RGM. MW- molecular weight; R_{soil} – uptake resistance for a soil surface; R_{water} – uptake resistance for a water surface.

Species	MW [g]	R_{soil} [s/m]	R_{water} [s/m]	Henry's Law [M/atm]
Hg^0	200.0	3.60×10^7	3.87×10^{-3}	0.110
RGM	271.5	28.4	3.04×10^{-4}	1.40×10^6

2.1. Meteorology and transport

Weather conditions for the continental-scale modelling were generated by the CSIRO Conformal Cubic Atmospheric Model (CCAM, McGregor 2005) at a grid spacing of $\sim 25 \times 25 \text{ km}^2$. Figure 1 shows that these meteorological data were used by the modelling system to drive both the emission and transport simulations.

The continental scale transport modelling was undertaken with the CSIRO Chemical Transport Model (CTM) which was originally developed for the Australian Air Quality Forecasting System (Cope et al. 2004). The CTM was modified to simulate weather dependent natural emissions of mercury and to treat the differing deposition properties of the three mercury species. The continental-scale transport modelling also accounts for a global background mercury concentration (about 1.3 ng m^{-3} , Seigneur et al. 2001) which is advected into the Australian region by the prevailing winds.

The urban and near-source modelling was undertaken using TAPM version 4 (Hurley 2008). The urban environments were modelled using three nested grids, the outer two at grid resolutions of 20 km and 8 km, and the inner grid at 3 km grid resolution, for:

- Sydney, domain of inner grid 180 km (east-west) x 210 km (north-south)
- Melbourne, domain of inner grid 210 km (east-west) x 180 km (north-south).

The near-source modelling was undertaken for five sites with an inner grid resolution of 1 km on domains of 50 km x 50 km for Kalgoorlie (WA); Pinjarra (WA); Mt Isa (QLD); NSW Central Coast; Latrobe Valley (VIC)

The urban scale and near source modelling was undertaken for an anthropogenic-only emission scenario, and with a zero background concentration. This configuration enabled the net contribution of the anthropogenic sources to be determined. The combined impact, at the urban and local scales, of all mercury sources (including the global background) was then estimated by adding the urban- and local-scale contributions to the contribution generated from a continental-scale simulation undertaken without anthropogenic emissions.

2.2. Emissions

Mercury emissions were estimated for anthropogenic emissions (industrial, commercial-domestic and motor vehicle sources), soils, vegetation, water surfaces and fires.

2.2.1 Anthropogenic Emissions

A discussion of the methodology used to generate annual emission totals for mercury from anthropogenic sources is given in Nelson et al. (2009). These sources were provided to the transport modelling team in three categories

Large ($> 10 \text{ kg yr}^{-1}$) industrial sources where the characteristics of the emission sources required for calculating plume rise (stack height, stack diameter, plume velocity and temperature) were provided from measurements or engineering estimates. This category includes large metal ore processing facilities and large coal-fired power stations.

Small ($0.1\text{--}10 \text{ kg yr}^{-1}$) industrial sources. These sources were given nominal emission release characteristics.

Commercial-domestic sources (such as crematoria; which are not captured by the source groups described above) and other distributed sources (such as motor vehicles). The emissions from these source groups were spatially distributed using a gridded population database.

Table 2 shows the annual emissions of the anthropogenic and natural sources (the latter will be discussed next). It can be seen that the industrial source group comprises about 7% of the total emissions into the Australian land surface and that emissions from the industrial source group comprises 93% of the anthropogenic emissions.

2.2.2. Natural Emissions- vegetation, soil, water

Natural emissions for the Australia region were modelled using the approach outlined in Shetty (2008). Emissions from vegetation are caused by the uptake of mercury in the soil-water by the porous plant root system and the release of mercury into the canopy atmosphere by evapotranspiration.

The fluxes of mercury from soils were divided into two categories- mercury emitted from shaded soil (located under a canopy) and mercury emitted from a bare soil surface. For bare soil, the emissions were parameterised using the soil temperature and the soil mercury concentration while the emissions from shaded soils were expressed as a function of the under-canopy solar radiation flux and the soil mercury concentration. Emissions from water surfaces were driven by the difference between the equilibrium dissolved mercury concentration (derived from the modelled near-surface atmospheric mercury concentration

using a Henry's law approach) and the ambient dissolved mercury concentration.

The emissions were estimated on an hourly gridded basis using meteorological data generated by the weather model and then summed to give annual total emissions for the Australian landmass. Table 2 shows that the combined mercury emissions from soil and vegetation comprise about 87% of the total mercury emissions from the Australian landmass and that emissions from bare soil comprise the largest natural source. Figure 2 shows the spatial distribution of the combined emission fluxes from soil and vegetation. It can be seen that the fluxes are generally in the range $1\text{--}4 \text{ ng m}^{-2} \text{ h}^{-1}$. Peaks of over $10 \text{ ng m}^{-2} \text{ h}^{-1}$ are predicted for the dry salt lake regions where elevated mercury-soil concentrations are assumed to exist.

The total budgets of natural mercury emissions reported in Table 2 can be compared with estimates generated by alternative approaches. For example Peterson et al. (2004) estimated mercury emissions from forests, lakes, grasses and soils in the range $131\text{--}269 \text{ tonne yr}^{-1}$ for the Australian land mass, and an alternative approach used in the current project estimated the annual emissions from vegetation to be in the range $63\text{--}1315 \text{ tonne yr}^{-1}$. The emissions from vegetation and soils shown in Table 2 total $148 \text{ tonne yr}^{-1}$ of which transpiration from vegetation contributes 8 tonne yr^{-1} (5.3%) and emissions from soils contribute the remainder (94.7%). While this total falls within the range reported by Peterson et al. (2004), the vegetation flux is an order of magnitude lower than an alternative estimate made by Nelson et al. (2009). The differences between these results and the results presented in Table 2 may be a result of using different soil mercury concentrations plus differences in the approaches used to calculate mercury emissions from evapotranspiration.

2.2.3. Natural Emissions- fires

Our estimate of the mercury emissions from bushfires is based on the methodology used by Meyer et al. (2008) to model $\text{PM}_{2.5}$ emissions from savannah burning in the Top End of Australia. In brief, the burned areas are first identified using satellite fire-scar (NOAA-Advanced Very High Resolution Radiometer) satellite images and hotspot (Moderate Resolution Imaging Spectroradiometer) data. These data are then combined with estimated fuel loads and used to generate a distribution of carbon emission fluxes. Mercury emissions were calculated from the carbon loading using an emission factor of $112 \text{ } \mu\text{g}$ of mercury per kg of dry fuel and assuming a 45% carbon content of the fuel (Friedli et al., 2003). This emission factor is representative of mercury emissions from fires in a temperate forest. The resultant emission fields were generated at a

temporal resolution of 1 h and a spatial resolution of 1 km×1 km.

Figure 3 shows the estimated spatial distribution of fire emissions for 2006. The estimated annual emission of 41.8 tonnes (Table 2) falls within the range of 2.6 tonnes reported earlier by Nelson (see

Nelson et al. 2009), who used the National Pollutant Inventory emission factors but appear to have assumed a much smaller area burnt, and 129 tonnes reported by Packham et al. (2009), who estimated a larger average burn area of 146×10^6 ha per year.

Table 2. The annual emissions of mercury from Australian anthropogenic and natural sources. Ocean fluxes have not been added to the emission totals because they depend on the model domain size.

	Hg ₀ (tonnes)	RGM (tonnes)	HgP (tonnes)	Total Hg (tonnes)	(%)
Anthropogenic					
Industrial	10.7	2.4	0.9	14.0	6.8
Com+Dom	0.8	0.1	0.1	1.0	0.4
Natural					
Vegetation	7.9	0	0	7.9	3.9
Canopy-soil	54.2			54.2	26.5
Bare soil	86.0	0	0	86.0	42.0
Fires	33.4	2.9	5.4	41.8	20.4
Ocean	598.7	0	0	598.7	n/a

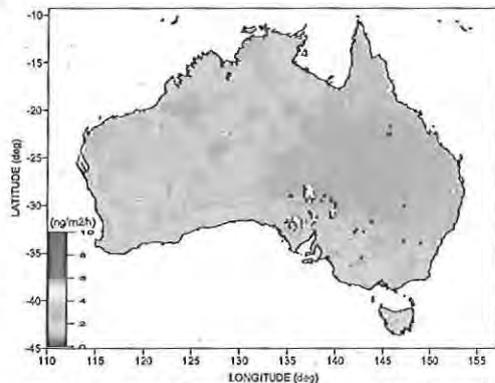


Figure 2. Average hourly mercury emissions ($\text{kg m}^{-2} \text{h}^{-1}$) from soil and vegetation.

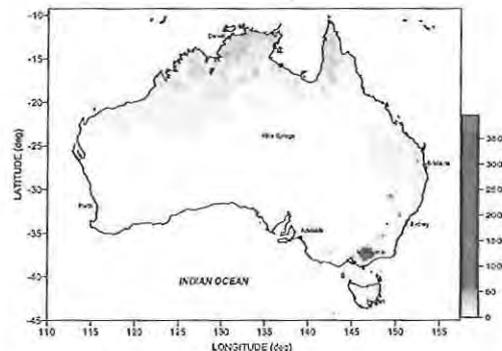


Figure 3. The spatial distribution of annual fire emissions for mercury ($\text{kg per grid square } (0.25^\circ \times 0.25^\circ)$) for 2006.

3. Transport modelling results

3.1 Annual average concentrations

Figure 4 shows the annual average near-surface mercury concentrations for the continental scale modelling for 'with' and 'without' bushfire emission scenarios. Table 3 shows the modelled concentration range for this and other model results (to be discussed shortly). For the 'without' bushfire emission scenario (Figure 4- bottom) it can be seen that the concentrations are generally in the range $1.2\text{--}1.3 \text{ ng m}^{-3}$. This falls at the lower end of the range predicted by a continental scale model of the U.S.A. (Seigneur et al. 2001). Regions where the annual average concentration falls below the global background concentration show the impact of depositional losses over the Australian land mass.

The highest modelled concentration of 2.6 ng m^{-3} occurs in the vicinity of Kalgoorlie gold roasters and reflects the significant mercury emissions associated with that source. Note however, that the near source impact modelling of this and the other large industrial sources suggests that (as expected) the $25 \times 25 \text{ km}^2$ continental scale modelling underestimates the annual average near field concentrations of such localised sources by up to an order of magnitude. This is illustrated in Table 3 where it can be seen that the near source modelling predicts annual average concentrations of up to 20 ng m^{-3} within the vicinity of large industrial sources. Note that the World Health organisation has a guideline of $1 \text{ } \mu\text{g m}^{-3}$ (annual average) (http://www.euro.who.int/document/a1q/6_9mercury.pdf) which is 50 times larger than the maximum concentrations predicted for Australia by the current project.

A comparison of Figure 4 top and bottom suggests that the emissions from bushfires can lead to regional impacts in annual average mercury which are comparable to the impacts resulting from the largest anthropogenic sources

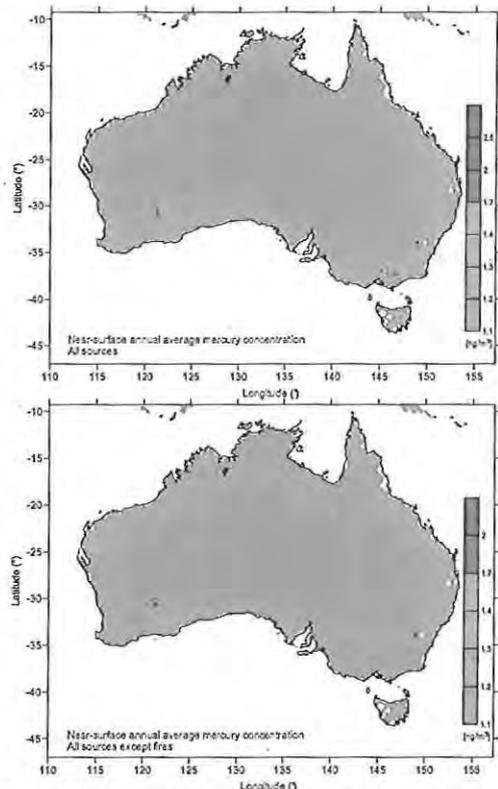


Figure 4. Annual average near-surface ambient mercury concentrations (ng m^{-3}) for the Australian region for 2006. Top – bushfire emissions are included. Bottom – bushfire emissions have been omitted (note the changed colour scale).

Figure 5 shows the annual average near-surface mercury concentrations for the Melbourne urban area. The contribution of the urban emissions is given in the top part of the figure. It shows that the maximum concentration is 0.7 ng m^{-3} and originates from an industrial source east of the city. However, within most of the Melbourne urban area, the contribution from anthropogenic sources is less than 0.1 ng m^{-3} .

The lower part of Figure 5 includes the contribution from natural sources (vegetation, soil, water, and the continental background), which was derived from output from a special 'no-anthropogenic' continental scale simulation as discussed previously. The contribution from natural sources is approximately 1.2 ng m^{-3} across the whole of the Melbourne model domain, and is thus the dominant contributor to ambient concentrations in this urban area.

3.2 Deposition

Figure 6 shows the annual wet deposition flux for the continental scale model. It can be seen that the wet deposition mass peaks on the western coast of Tasmania ($2 \mu\text{g m}^{-2} \text{ yr}^{-1}$), within the Kalgoorlie region ($2 \mu\text{g m}^{-2} \text{ yr}^{-1}$) and along the Great Dividing Range in eastern Australia.

Table 3. The modelled range of peak concentrations and deposition fluxes for various scenarios and spatial scales.

	Concentration (ng m^{-3})	Wet Deposition ($\mu\text{g m}^{-2} \text{ yr}^{-1}$)	Dry Deposition ($\mu\text{g m}^{-2} \text{ yr}^{-1}$)
Background	1.4	n/a	n/a
Continental	1.2 – 2.6	0.2 – 2.0	0.2 – 50
w-Fires	1.2 – 3.0	0.2 – 5.0	0.2 – 50
U.S.A. ^{1,2}	1.7 – 4.0	4 – 20	2 – 70
Urban contribution	0.5 – 1	20 – 100	2 – 100
Near source contribution	0.05 – 20	5 – 500	1 – 100

¹Seigneur et al. 2001; Bullock et al. 2002.

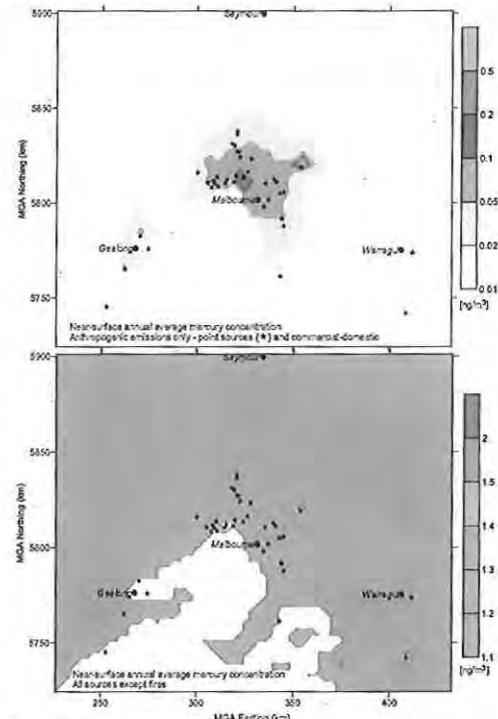


Figure 5 Annual average (2006) near-surface ambient mercury concentrations (ng m^{-3}) for the modelled Melbourne urban area. Top – only anthropogenic emissions (point sources and commercial-domestic). Bottom – all emissions except bushfires

These locations correspond either to regions of higher rainfall or regions of elevated mercury concentrations (natural and / or anthropogenic) or combinations of these two factors. Table 3 shows that, at the continental scale, the maximum wet deposition fluxes are only about one tenth of the

magnitude of the maximum dry deposition fluxes, with the latter occurring within the vicinity of large industrial sources or bush fires. It can also be seen that the wet and dry deposition totals lie at the lower end of the range reported for the U.S. Additionally, the table shows that the urban and near source maximum wet deposition fluxes (which are quite localised in scale) are up to 100 times higher than the continental scale fluxes. This is a result of higher mercury concentrations and higher rainfall rates over topography which is better resolved at the urban and near source scales.

The urban scale and local scale maximum dry deposition fluxes are also up to 100 times higher than the continental scale dry deposition fluxes and result from better resolution of mercury concentrations downwind of industrial sources by the local scale modelling.

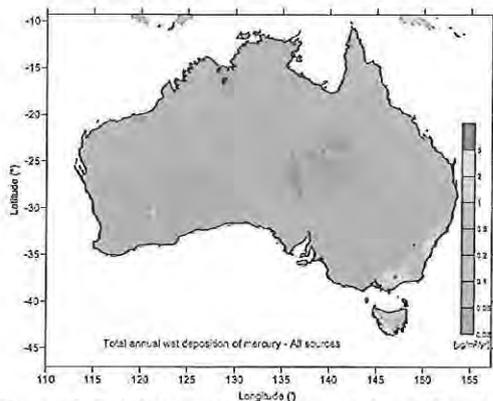


Figure 6. Total annual mercury wet deposition ($\mu\text{g m}^{-2} \text{yr}^{-1}$) for the Australian region for 2006.

4. Discussion

This project represents one of the first attempts to comprehensively model the emissions, concentrations and deposition of mercury over the Australian land mass. As such there are considerable uncertainties associated with many aspects of the modelling system, and particularly with the natural emission fluxes. This was apparent from the discussion in section 2.2 which highlighted the large discrepancies in various researchers' estimates of the mercury fluxes from vegetation and fires. Some of this discrepancy may result from the assumptions used in the derivation of soil mercury concentrations for the Australian continent. The spatial distribution of soil mercury concentration is likely to be highly inhomogeneous and yet there are currently only sparse measurements available (Packham et al. 2009). Soil mercury is a critical parameter as it drives the soil and vegetation re-emission fluxes and Table 2 suggests that re-emission may be the largest source of mercury in Australia.

Note that there appears to be little Australian data available to verify the concentration and

deposition predictions of the modelling system. A limited set of short-term total gaseous mercury concentration data has been collected at Macquarie University (Nelson 2009- personal communication) which shows a background concentration of about 1 ng m^{-3} and a diurnal concentration profile with amplitude of about 1 ng m^{-3} . The Sydney urban scale modelling when combined with the continental-scale modelled was found to generate similar features although the amplitude of the diurnal wave was smaller (about 0.5 ng m^{-3}).

4. References

- Bullock, O.R., Brehme, K.A., 2002. Atmospheric mercury simulation using the CMAQ model: formulation description and analysis of wet deposition results. *Atmospheric Environment* 36, 2135–2146.
- Cope M. E., Hess G. D., Lee S., Tory K., Azzi M., Carras J., Lilley W., Manins P. C., Nelson P., Ng L., Puri K., Wong N., Walsh S., Young M., 2004. The Australian Air Quality Forecasting System. Part I: Project Description and Early Outcomes. *J. Appl. Meteorol.*, 43, 649-662.
- Friedli, H.R., Radke, L.F., Lu, J.Y., Banic, C.M., Leitch, W.R., MacPherson, J.I., 2003. Mercury emissions from burning of biomass from temperate North American forests: laboratory and airborne measurements. *Atmospheric Environment* 3(2), 253–267.
- Hurley P., 2008. TAPM v4. Part 1: Technical Description. CSIRO Marine and Atmospheric Research. ISBN: 978-1-921424-71-7. ISSN: 1835-1476.
- Lin, C.-J., Pongprueksa, P., Lindberg, S.E., Pehkonen, S.O., Byun, D., Jang, C., 2006. Scientific uncertainties in atmospheric mercury models I: model science evaluation. *Atmospheric Environment* 40, 2911–2928
- McGregor, J. L., 2005. CCAM: Geometric aspects and dynamical formulation [electronic publication]. CSIRO Atmospheric Research Tech. Paper No. 70, 43 pp.
- Meyer, C.P., Luhar, A.K., Mitchell, R.M., 2008: Biomass burning emissions over northern Australia constrained by aerosol measurements: I-Modelling the distribution of hourly emissions. *Atmos. Environ.*, 42, 1629–1646.
- Nelson, Peter, Nguyen, Hao., Morrison, Anthony, Malfroy, Hugh., 2009. Development of an inventory for mercury emissions in Australia. Submitted to 19th International Clean Air and Environment Conference, 6th-9th September 2009. Perth, Western Australia.
- Packham, D., Tapper, N., Griepsma, D., Friedli, H., Hellings, J., and Harris, S., 2009. Release of mercury in the Australian environment by burning: A preliminary investigation of biomatter and soils. *Air Quality & Climate Change*, 43 (1), 24–27
- Peterson, C., Nelson, P., and Morrison, A., 2004. Quantifying natural and anthropogenic sourced mercury emissions from Australia in 2001. Research report (Cooperative Research Centre for Coal in Sustainable Development Australia). Pullenvale, Qld. QCAT Technology Transfer Centre.
- Seigneur, C., Karamchandani, P., Lohman, K., and Vijayaraghavan, K., 2001. Multiscale modelling of the atmospheric fate and transport of mercury, *J. Geophys. Res.*, 106, 27795-27809.
- Shetty, S., Lin, C., Streets, D. and Jang, C., 2008. Model estimate of mercury emission from natural sources in East Asia, *Atmos. Environ.*, 42, 8674-8685.