Human Health Risk Assessment – Mercury Emissions from CFPGs

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Document History and Status

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Limitations

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It is prepared in accordance with the scope of work and for the purpose outlined in the **Section 1** of this report.

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Glossary of Terms

Acute Exposure	Contact with a substance that occurs once or for only a short time (up to 14 days).
Adsorption	The process of taking in. For a person or an animal, absorption is the process of a substance getting into the body through the eyes, skin, stomach, intestines, or lungs.
ADI	Acceptable Daily Intake – The amount of a chemical a person can be exposed to on a daily basis over an extended period of time (usually a lifetime) without suffering deleterious effects.
Additive Effect	A biologic response to exposure to multiple substances that equals the sum of responses of all the individual substances added together [compare with antagonistic effect and synergistic effect]
Adverse Health Effect	A change in body function or cell structure that might lead to disease or health problems
Antagonistic Effect	A biologic response to exposure to multiple substances that is less than would be expected if the known effects of the individual substances were added together [compare with additive effect and synergistic effect].
ANZECC	Australia and New Zealand Environment and Conservation Council
AT	Averaging Time
Background Level	An average or expected amount of a substance or material in a specific environment, or typical amounts of substances that occur naturally in an environment.
BGL	Below ground level
Biodegradation	Decomposition or breakdown of a substance through the action of micro-organisms (such as bacteria or fungi) or other natural physical processes (such as sunlight).
Body Burden	The total amount of a substance in the body. Some substances build up in the body because they are stored in fat or bone or because they leave the body very slowly.
BW	Body weight
Carcinogen	A substance that causes cancer
CF	Unit Conversion Factor
Chronic Exposure	Contact with a substance that occurs over a long time (more than 1 year) [compare with acute exposure and intermediate duration exposure]
DECCW	Department of Environment, Climate Change and Water
Dermal Contact	Contact with (touching) the skin [see route of exposure].
Detection Limit	The lowest concentration of a chemical that can reliably be distinguished from a zero concentration.
Dose	The amount of a substance to which a person is exposed over some time period. Dose is a measurement of exposure. Dose is often expressed as milligram (amount) per kilogram (a measure of body weight) per day (a measure of time) when people eat or drink contaminated water, food, or soil. In general, the greater the dose, the greater the likelihood of an effect. An "exposure dose" is how much of a substance is encountered in the environment. An "absorbed dose" is the amount of a substance that actually got into the body through the eyes, skin, stomach, intestines, or lungs.
ED	Exposure Duration
EF	Exposure Frequency
EPA	Environment Protection Authority
ET	Exposure time
Exposure	Contact with a substance by swallowing, breathing, or touching the skin or eyes. Exposure may be short-term [acute exposure], of intermediate duration, or long-term [chronic exposure].
Exposure Assessment	The process of finding out how people come into contact with a hazardous substance, how often and for how long they are in contact with the substance, and how much of the substance they are in contact with.

Glossary of Terms

Exposure Pathway	The route a substance takes from its source (where it began) to its end point (where it ends), and how people can come into contact with (or get exposed to) it. An exposure pathway has five parts: a source of contamination (such as chemical leakage into the subsurface); an environmental media and transport mechanism (such as movement through groundwater); a point of exposure (such as a private well); a route of exposure (eating, drinking, breathing, or touching), and a receptor population (people potentially or actually exposed). When all five parts are present, the exposure pathway is termed a completed exposure pathway.
Guideline Value	Guideline value is a concentration in soil, sediment, water, biota or air (established by relevant regulatory authorities such as the NSW Department of Environment and Conservation (DEC) or institutions such as the National Health and Medical Research Council (NHMRC), Australia and New Zealand Environment and Conservation Council (ANZECC) and World Health Organisation (WHO)), that is used to identify conditions below which no adverse effects, nuisance or indirect health effects are expected. The derivation of a guideline value utilises relevant studies on animals or humans and relevant factors to account for inter- and intra-species variations and uncertainty factors. Separate guidelines may be identified for protection of human health and the environment. Dependent on the source, guidelines will have different names, such as investigation level, trigger value, ambient guideline etc.
Hazard Quotient/ Hazard Index (HQ/HI)	Hazard quotient is the ratio of daily chemical calculated for a specific receptor and exposure pathway, to the acceptable or safe dose (ADI, TDI, RfD etc.) for that chemical. A value less than 1 indicates that the intake is less than the safe intake. A hazard index is the sum of the hazard quotients for all chemicals exposure pathways for a receptor.
HIL	Health Investigation Level
HHRA	Human Health Risk Assessment
Ingestion	The act of swallowing something through eating, drinking, or mouthing objects. A hazardous substance can enter the body this way [see route of exposure].
Inhalation	The act of breathing. A hazardous substance can enter the body this way [see route of exposure].
Intermediate Exposure Duration	Contact with a substance that occurs for more than 14 days and less than a year [compare with acute exposure and chronic exposure].
LOAEL	Lowest-observed-adverse-effect-level - The lowest tested dose of a substance that has been reported to cause harmful (adverse) health effects in people or animals
LOR	Limit of Reporting

Mercury Species:

Hg^0	Elemental mercury, quicksilver, metallic mercury
Hg^{2+}	Mercuric mercury (mercury (II))
Hg_2^{2+}	Mercurous mercury (mercury (I))
$HgCl_2$	Mercuric chloride
HgO	Mercury oxide (solid)

Executive Summary

Environmental Risk Sciences P/L has been commissioned by the National Generators Forum (NGF) to undertake a desk-top study to quantify the potential chronic health risks associated with the emissions of mercury to air from coal-fired power generators (CFPGs). The aim of the work was to:

- identify the levels of mercury in emissions from CFPGs;
- identify a location suitable for a case study;
- model mercury emissions from the CFPGs in the case study area; and
- characterise the risks posed by mercury in air in the case study area.

The Hunter Valley and Central Coast airshed was chosen for the case study in this investigation given the number of power stations in the area and the number of people who live in the area that may be exposed to emissions from the CFPGs.

This report presents a preliminary desk-top study to quantify potential chronic health risks associated with emissions of mercury to air from coal-fired power generators (CFPG). The presence of mercury in emissions from CFPGs arises because of the presence of trace levels of mercury in coal. In Australia there are a number of CFPGs with a wide range of power generating capacity and potential for mercury emissions. To evaluate the potential for mercury emissions to be of concern to the health of local/regional populations this assessment has focused on assessing potential emissions and exposures derived from the operation of four CFPGs in the Hunter Valley and Central Coast airshed of NSW.

Based on the assessment undertaken and within consideration of the uncertainties identified, the following can be concluded:

- No adverse health effects are associated with potential exposures by the community in the Hunter Valley and Central Coast to mercury that may be derived from the operation of the four CFPGs located within that airshed.
- In relation to other CFPGs in Australia, while mercury emissions reported in the NPI database for power stations located in the LaTrobe Valley in Victoria are higher than those considered in the Hunter Valley and Central Coast region, the emission rates from those CFPGs are not high enough to be of concern as there is a significant margin of safety (more than 10 000 fold) in the assessment undertaken (i.e. emissions would have to be more than 10 000 times higher to result in concentrations higher than the guideline).

While there is some uncertainty in the measurement and modelling in the estimates of mercury concentrations in air, it is of the order of 10-100 fold. As noted the margin of safety (MOS) is more than 10 000 fold. Hence while there is some uncertainty in the available data it is not sufficient to be of concern, require further data to be collected or impact the conclusions presented in this report.

Given this margin of safety, the conclusions of this risk assessment are applicable throughout Australia in locations where CFPGs are present.

On this basis human health impacts associated with mercury emissions that may be derived from the operation of CFPGs in Australia are considered to be negligible and do not warrant more detailed quantification or management.

Section 1. Introduction

1.1 Background

Environmental Risk Sciences Pty Ltd (enRiskS) has been commissioned by the National Generators Forum (NGF) to undertake a human health risk assessment (HHRA) to quantify local and regional exposures to mercury emissions that may be derived from the operation of coal fired power generators (CFPG) in Australia.

Recent work conducted by the United Nations (UN) identified the requirement to undertake mercury emissions reduction measures in relation to emissions of mercury from CFPG in Europe. Policies are already in place in the United States for the reduction of mercury emissions from CFPG. The emission of mercury from CFPG is largely dependent on the concentration of mercury content in coal and individual CFPG operational parameters. Hence this assessment is required to provide an understanding of the level of mercury emissions and potential long-term (chronic) human health risks from CFPG in Australia.

The evaluation of mercury emissions from all CFPG in Australia covers a wide range of power generators, local and regional environments and hence the conduct of the HHRA has focused on providing a preliminary evaluation of mercury emissions by quantifying emissions and risk issues from a key local and regional environment. The local/regional environment identified and evaluated in this assessment relates to the Hunter Valley/Central Coast airshed.

The aim of this approach is to provide the NGF with an indicative level of risk (i.e. negligible, low, moderate or high) that be may associated with CFPGs in Australia and whether there is the need to conduct more detailed evaluations of mercury emissions/risks and/or the requirement to implement mercury reduction measures in other local/regional CFPG across Australia.

1.2 Objectives and Scope of Works

The overall objective of the HHRA is to undertake a first pass/preliminary desk-top study to quantify potential chronic health risks associated with emissions of mercury to air from coal-fired power generators (CFPG) located in the Hunter Valley/central Coast airshed in NSW, Australia, and determine if action is warranted to control mercury stack emissions.

More specifically the scope of works undertaken to complete this evaluation includes the following tasks:

Task 1:

Review and summarise existing mercury emissions rates from major CFPGs, in particular the CFPG to be considered as a case study (refer to Task 2). Mercury emissions will be determined from actual stack test data (where available) and NPI data. Where possible (depending on the availability of data) the following will be undertaken:

- Summary of how mercury emissions have been determined for each CFPG (e.g. mass balance or actual stack test data);
- Comment on relative accuracy of emissions (i.e. potential for emissions to be over or under estimated), which is relevant to the overall evaluation of uncertainty within the HHRA;

- Comparison of Australian CFPG mercury emissions with other industry emissions sources in Australia;
- Comparison of Australian CFPG mercury emissions with emissions from international CFPGs (particularly the US and Europe); and
- Identify and summarise any other mercury studies (of note) undertaken in Australia.

Task 2:

Identify a case study to conduct a detailed assessment of potential human health risks associated with mercury emission from CFPG in Australia. It is expected the case study to be considered will be CFPG within the Hunter Valley/Central Coast airshed. This case study is considered to provide an air shed that is representative of worst-case emissions and potential exposures (particularly regional exposures) due to the following:

- The number and size of CFPG in the air shed;
- The availability of emissions data and meteorological data for local and regional areas within the air shed;
- The air shed is relatively well populated with several population centres potentially affected by stack emissions.

Task 3:

Undertake a baseline air modelling study to establish 'typical' annual average mercury concentrations in air for up to 5 years at key population receptor locations within the Hunter Valley air shed.

The air dispersion modelling has been undertaken by Todoroski Air Sciences.

Task 4:

Conduct a quantitative assessment of potential chronic human health risk issues associated with the predicted annual average concentrations in air at key population receptor locations in the study area (refer to the methodology outlined below).

1.3 Approach

1.3.1 Methodology

The methodology adopted for the conduct of the HHRA is in accordance with established industry guidance developed and endorsed by Australian health and environmental authorities that includes:

- EnHealth Environmental Health Risk Assessment: Guidelines for Assessing Human Health Risks from Environmental Hazards: 2012 (enHealth 2012a);
- EnHealth Health Impact Assessment Guidelines: September 2001 (enHealth 2001);
- EnHealth Exposure Factors Guide, EnHealth Council, 2012 (enHealth 2012b); and
- National Environment Protection Council (NEPC) Schedule B(8) Guideline on Community Consultation and Risk Communication, National Environment Protection (Assessment of Site Contamination) Measure, 1999 (NEPC 1999a).

In addition, where relevant and where Australian guidance is not available, guidance has also been obtained from established peer reviewed international sources (and is referenced where utilised), including:

- United States Environment Protection Agency (USEPA) Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part F, Supplemental Guidance for Inhalation Risk Assessment), EPA-540-R-070-002, January 2009 (USEPA 2009);
- World Health Organisation (WHO) guidance (various documents). It is noted that many of the WHO guidance documents address pollutants that are covered in NSW and Australian guidance. Many of these local guidance values have been drawn from the WHO or have utilised approaches that are consistent with the WHO. In any risk assessment it is important that the basis for guidance and criteria is fully understood (as required by enHealth [2012]) and hence WHO guidance is often utilised as background sources of information to support local guidance. In some cases local guidance does not adequately cover the assessment of chronic health effects from exposure to pollutants and hence guidance such as the WHO is utilised to support the assessment of health risk. It is also noted that in relation to the assessment of uncertainties the document "Harmonisation Project Document No. 6, Part 1: Guidance Document on Characterising and Communicating Uncertainty in Exposure Assessment" (WHO 2008) provides appropriate guidance for the conduct of an adequate and sufficiently transparent health risk assessment.

In following this guidance, the following has been completed, and are presented in this report.

Data Evaluation and Issue Identification

This task involves a review of all available information that relates to the importance of evaluating mercury emissions in the environment and the potential for mercury to be released to air from the operation of CFPGs in Australia (presented in **Section 2**).

Exposure Assessment

The focus of the assessment presented in this report relates to the local/regional airshed of the Hunter Valley and Central Coast. The CFPGs located in this area, estimates of mercury emissions and the population that may be exposed to mercury emissions within this area have been identified and discussed (presented in **Section 3**).

The quantification of potential exposure requires the modelling of mercury emissions from the CFPGs. This has been undertaken by Todoroski Air Sciences (TAS) where potential concentrations of mercury in air within the airshed have been estimated.

Toxicity Assessment

The objective of the toxicity assessment is to identify the adverse health effects and quantitative toxicity values that are associated with the key pollutants identified and evaluated in this assessment. This has involved the following key steps (as presented in **Section 4**):

1. Identify the relevant health end-points and mechanism of action for the assessment of exposures to mercury, relevant to the form of mercury potentially present in air within the airshed considered; and
2. Identify the most appropriate quantitative value for the assessment of adverse health effects in accordance with guidance available from enHealth (2012). This includes consideration of susceptible populations, where relevant.

Risk Characterisation

This task (presented in **Section 5**) combines the quantification of exposure (how much the populations in the local/regional area are exposed to) and toxicity (which is used to define what adverse health effects may occur at what level of exposure) to enable an evaluation of long-term chronic risk. The assessment presented will also consider the level of uncertainty associated with all aspects of the HHRA. The final determination of risks to human health will be based on the quantification of risks as well as consideration of these uncertainties.

The overall approach is outlined in **Diagram 1**.

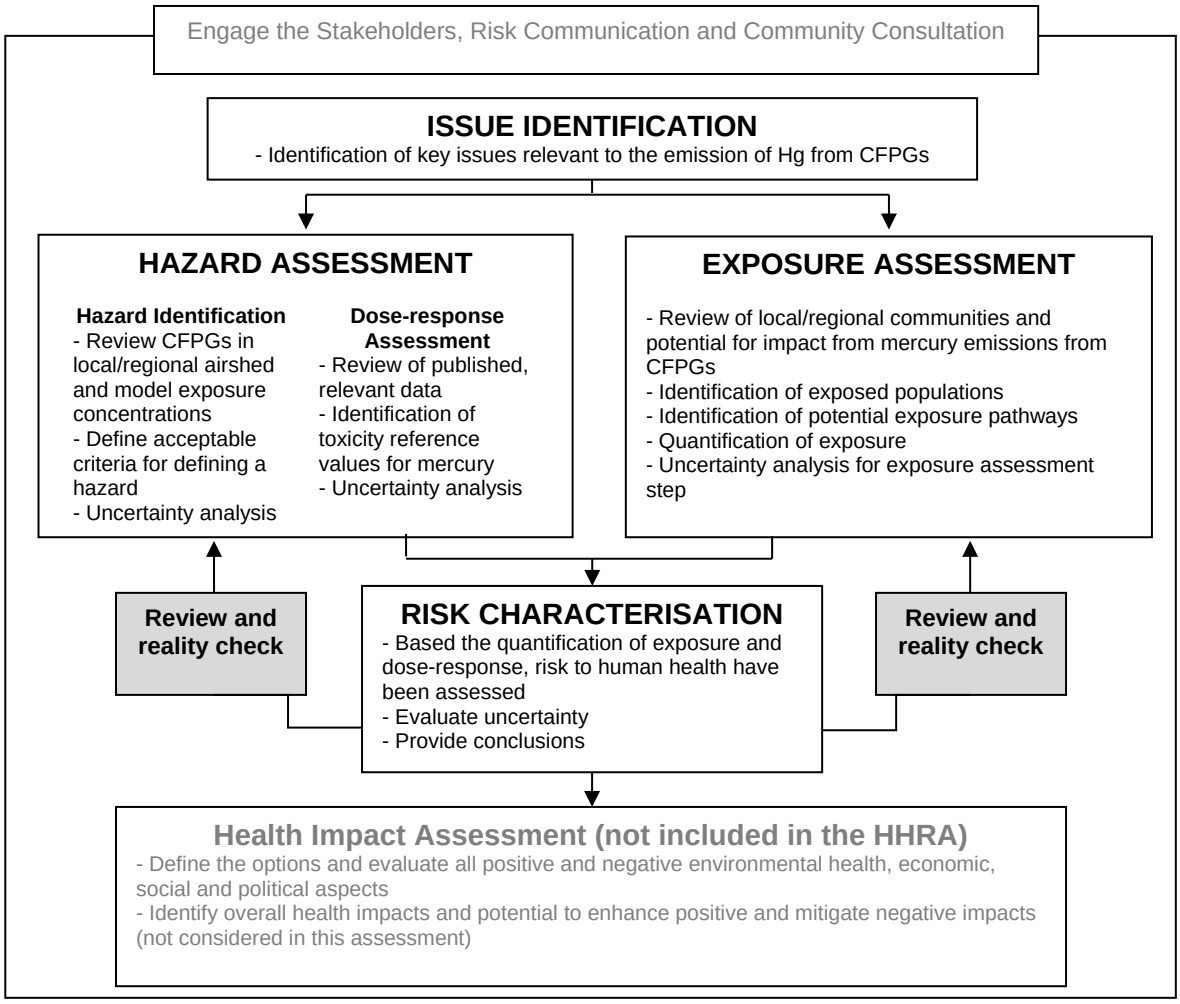

Diagram 1: Overall HHRA Approach (from enHealth 2012)

1.3.2 Features of the Risk Assessment

The HHRA has been carried out in accordance with international best practice and general principles and methodology accepted in Australia by groups such as NHMRC, NEPC and enHealth. However, there are certain features of risk assessment methodology that are fundamental to the assessment of the outputs and to drawing conclusions on the significance of the results. These are summarised below:

- A risk assessment is a mathematical procedure that addresses potential exposure pathways based on an understanding of the nature and extent of the impact assessed and the uses of the local area by the general public. The risk assessment is based on an estimation of maximum, or worst-case, ground level concentrations modelled in the local/regional community and hence is expected to overestimate the actual risks;
- Conclusions can only be drawn with respect to emissions to air derived from the CFPGs evaluated in Australia;
- The HHRA does not provide an evaluation of the overall health status of the community or any individuals. Rather, it is a logical process of calculating and comparing potential exposure concentrations of mercury in the local/regional areas that may be released/emitted to air during the operation of the CFPGs with regulatory and published acceptable air concentrations that any person may be exposed to over a lifetime without unacceptable risks to their health; and
- The risk assessment reflects the current state of knowledge regarding the potential health effects of chemicals identified and evaluated in this assessment. This knowledge base may change as more insight into biological processes is gained, further studies are undertaken and more detailed and critical review of information is conducted.

Section 2. Issues Associated With Mercury in the Environment

2.1 Introduction

Mercury is a pervasive and persistent chemical in the environment. It is a naturally occurring element that is released from a variety of sources including human activities. Once released into the environment, mercury undergoes a series of complex chemical and physical transformations as it cycles between the atmosphere, land, and water. Humans, plants, and animals are routinely exposed to mercury and accumulate it during this cycle, potentially resulting in a variety of ecological and human health impacts.

The characteristics of mercury that make it a health and environmental problem are its toxicity and persistence in the environment, and its ability to accumulate and bioconcentrate as methylmercury in aquatic species.

The following presents a summary of background information on mercury in the environment, how the population may be exposed to mercury, key sources of mercury emissions (including from CFPGs) and international agreements and conventions in relation to mercury.

2.2 Global Mercury Sources

Mercury is a naturally occurring element, one of the 92 naturally occurring elements represented in the Periodic Table that form the compounds that make up the planet. It is found throughout the world and has been present in the environment since before humans appeared. It is a heavy silvery metal which is liquid at room temperature, the only metal that is liquid under these conditions (UNEP 2013a).

Mercury is commonly found in modern life. Electrical and electronic equipment, electrical switches and relays, medical equipment, measuring devices, fluorescent light bulbs, batteries, cosmetics, dental fillings all contain some mercury (refer to **Figure 1**). While many of these uses are being phased out, a number of consumer products still contain various levels of mercury. Food products contain mercury (usually low levels) as the plants and animals are grown in or on soil containing mercury or in waters containing mercury. The presence of mercury in these environments can be naturally occurring or from pollution (local or global) (UNEP 2013a).

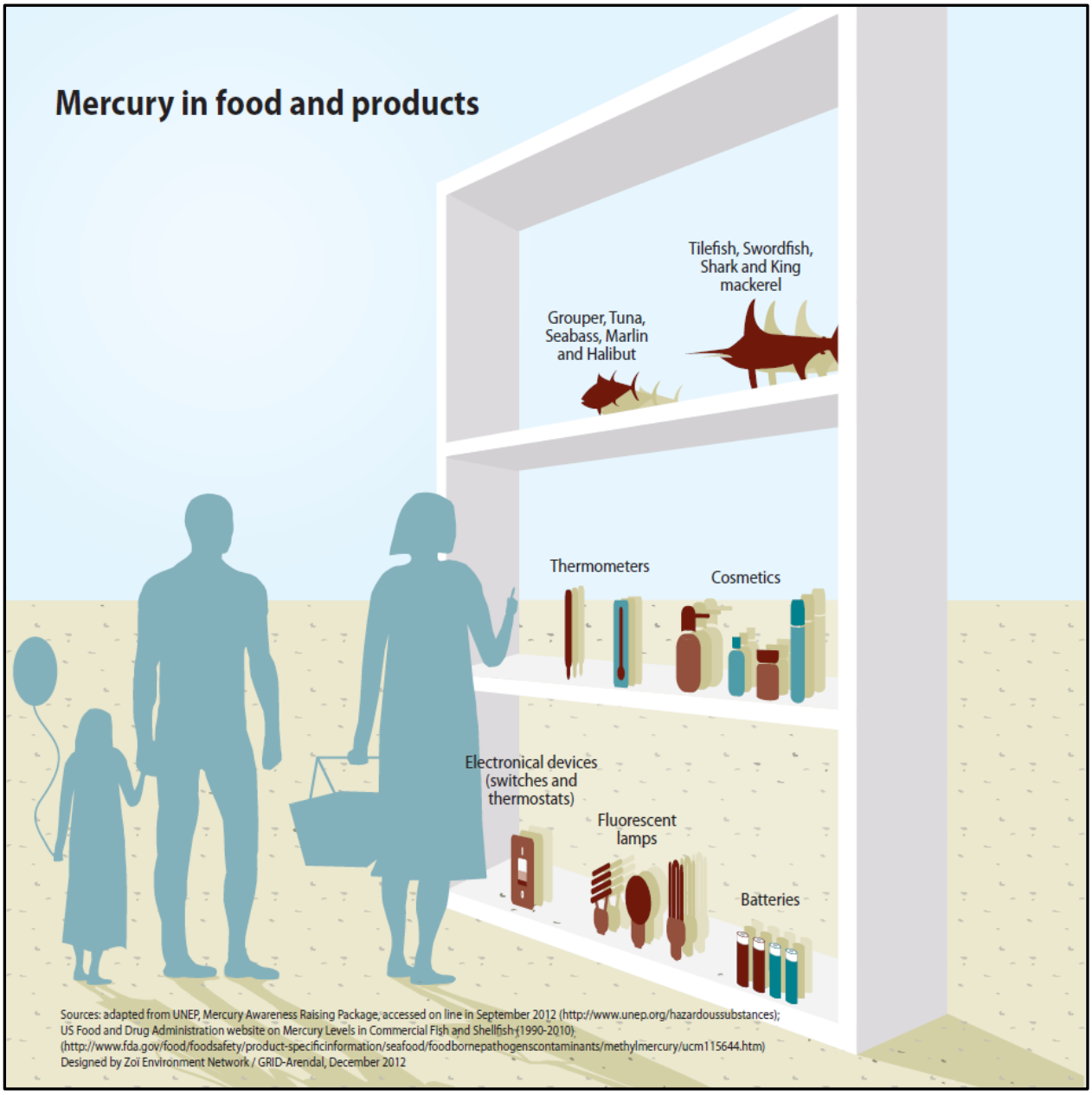

Figure 1 Simplistic Illustration of Food and Consumables where Mercury may be Found (UNEP 2013b)

Mercury is used at different rates in different regions (see **Figure 2**). East and Southeast Asia is the region that uses the most mercury predominantly in small scale gold mining and in the manufacture of vinyl chloride monomer to be used in making polyvinylchloride. In Australia and other Oceania countries usage is only 2% of that in East and Southeast Asia (UNEP 2013b).

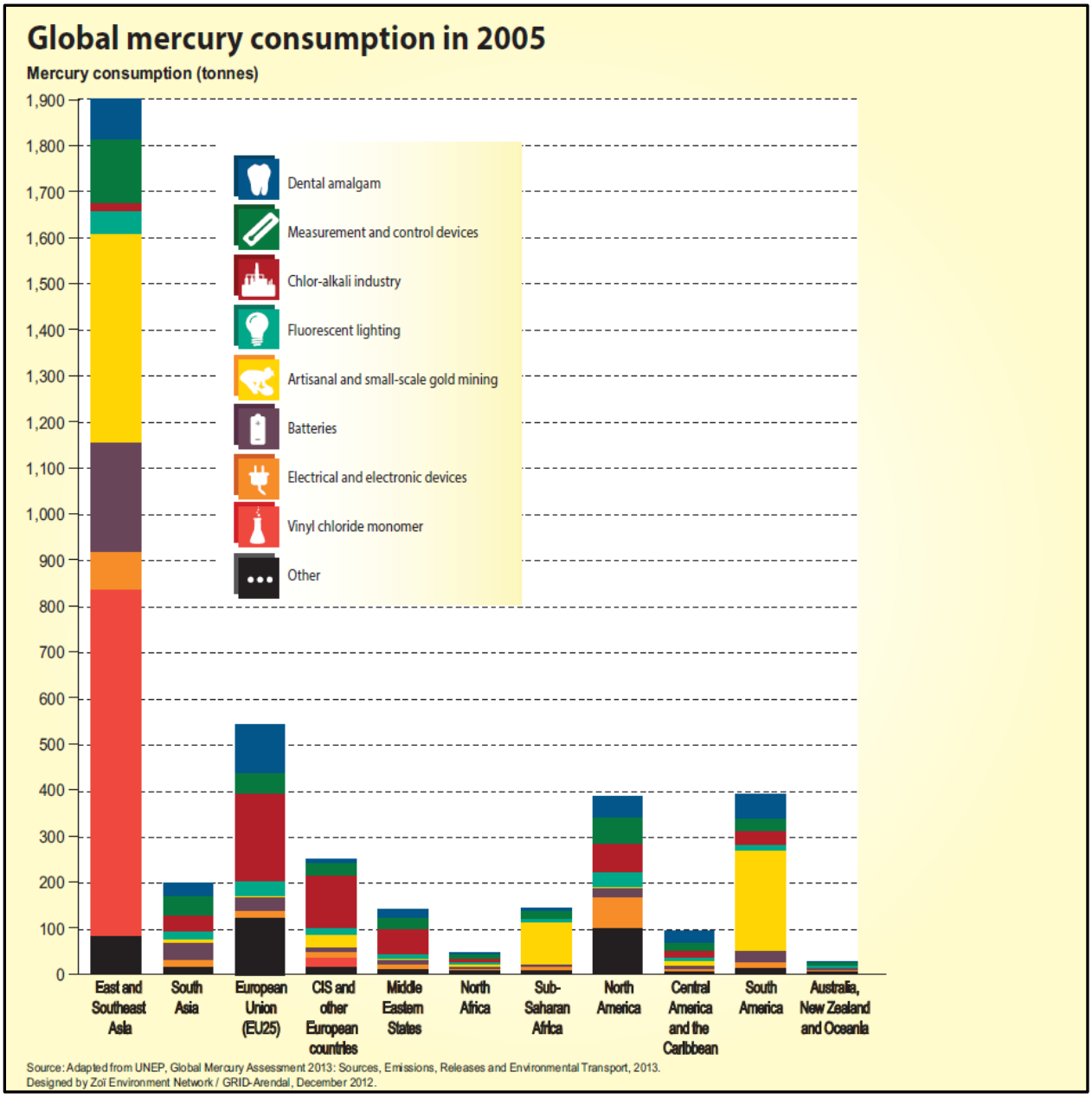

Figure 2 Regional Consumption of Mercury (UNEP 2013b)

In nature mercury is normally found in the form of cinnabar – an ore of mercuric sulfide. Mercury is also present in many other ores as an impurity, particularly non-ferrous metals. It is also present as an impurity in fossil fuels like coal or in limestone. More recently, the main source of mercury has been mercury recovered from waste and stockpiles rather than mining (UNEP 2013a, 2013b)

Geothermal activity, volcanic eruptions and natural weathering of mercury-containing rocks are natural processes by which mercury is mobilised in the environment. A range of human activities including mining and the burning of coal also mobilise mercury.

The global mercury cycle refers to all the processes involved where mercury is released from long term stores (such as ore bodies or buried sediments), moves into the atmosphere or waters, forms salts or methylated compounds or attaches to particles that may all move back into long term stores through deposition or other processes (see **Figure 3**).

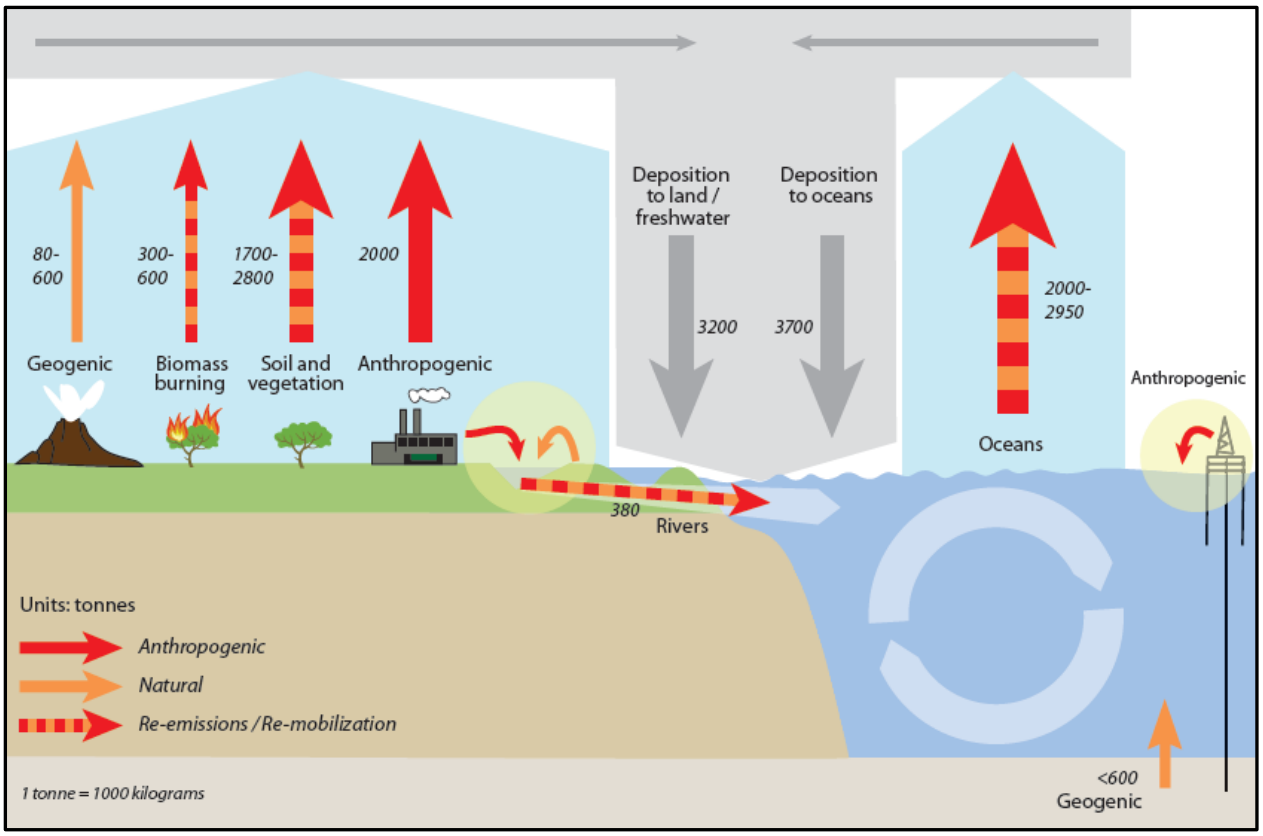

Figure 3 Representation of Global Mercury Budget (UNEP 2013a, 2013c)

Modelling of the global mercury cycle indicates that about 10% of the mercury being released into the atmosphere comes from natural processes with about 30% coming from direct releases like coal burning or mining. About 60% of the mercury released to the atmosphere comes from re-mobilisation of mercury from what could be described as short term stores, where mercury is present in aquatic systems, sediments or surface soils. Processes can release the mercury from these short term stores back into the atmosphere. Natural chemical reactions in the ocean and in sediments and soils convert mercury salts back into elemental mercury which then evaporates. Bushfires release mercury from soils and plants into the atmosphere. Floods can move mercury containing soils or sediments to locations where remobilisation is faster. The large contribution to emissions by the remobilisation of existing releases of mercury into these shorter term stores means controls on direct releases can only change global environmental concentrations slowly (UNEP 2013a, 2013b, 2013c).

2.3 Global Mercury Partnership and the Minamata Convention on Mercury

The chemical characteristics of mercury mean when released or remobilised it can travel long distances spreading it around the planet. It is also unintentionally released rather than being deliberately released from a range of activities due to its presence as an impurity in various metal ores, coal and other geologies. Because it is an element which cannot break down any further it is persistent in the environment and it can accumulate up the food chain given the right conditions. It also interacts with protein building blocks in the body which can lead to toxic effects in organisms and people. These characteristics mean that management actions undertaken on a local level can have limited effect. As a result, the international community through the United Nations Environment Program has prioritised action on mercury and is coordinating efforts to build knowledge and provide guidance so that global emissions of mercury can be reduced over time. Work commenced in 2003 (UNEP 2013b).

In January 2013 a global, legally binding treaty was finalised to prevent emissions and releases. It has been named the Minamata Convention on Mercury after a city in Japan where serious health issues arose from mercury pollution in the mid-20th Century. The treaty now needs to be ratified by individual countries before it comes into force.

The Global Mercury Partnership has also been formed as part of this process which includes governments, intergovernmental organisations, non-government organisations and a range of companies, industry organisations and research organisations to undertake activities in a series of priority areas (formed as Partnership Advisory Groups [PAGs]). These areas include:

- Reducing mercury in artisanal and small scale gold mining
- Mercury control from coal combustion
- Mercury reduction in the chlor-alkali industry
- Mercury reduction in products
- Research into the atmospheric transport and fate of mercury
- Mercury waste management
- Mercury supply and storage
- Mercury reduction from the cement industry.

In each of these areas, guidance documents have been developed and some studies have been undertaken or are in process (UNEP 2013d). In relation to the PAG on coal combustion the most recent meeting minutes indicate that the group supports studies in a number of countries in relation to characterising the mercury content in coal used for power generation, implementing technology to reduce mercury emissions from existing facilities and providing tools to assist in evaluating emissions and achieving emission reductions.

This study into mercury release from coal fired power generators in Australia is a proactive step by the National Generators Forum to develop the information needed for decision making as international actions on mercury are developed, agreed and implemented.

2.4 Mercury Emissions from Industrial Sources

The UN Environment Program has been investigating the emissions of mercury from industrial sources as part of its work, with the most recent report, the Global Mercury Assessment released in 2013. This included an inventory of mercury emissions for the year 2010. Previously similar assessments were undertaken for the years 2005 and 1995 (UNEP 2013a, 2013b, 2013d).

The latest inventory identified that emissions are now dominated by areas where small scale gold mining occurs. Emissions from the region including Australia contribute only 1% to the global industrial emissions of mercury (UNEP 2013b).

The inventory has also identified the contribution of the various types of industrial sources of mercury (**Figure 4**). In 2010 the major source of mercury to the environment is small scale gold mining followed by combustion of fossil fuels (such as coal fired power generators) and metal production (such as smelting). These emissions are similar to those reported in 2005, but they have changed since the 1995 inventory. In 1995 the global emissions were dominated by combustion of fossil fuels (60%) with metal production and cement production each contributing 10%. Small scale gold mining contributed about 20%. The total emissions found in 1995 were about half of that estimated for 2010 however the inventory of emission sources was not as comprehensive in 1995.

The chloralkali industry contributes only about 1% in 2010 to the global emissions while in 2005 it was about 10%. This has occurred as the chloralkali industry has invested in plant refits to remove the need for the use of mercury in the manufacture of chlorine and caustic soda (UNEP 2002, 2008, 2013a, 2013b, 2013d).

The use of mercury in fluorescent lighting has also been addressed by manufacturers. The amount of mercury per bulb has been reduced significantly (about 8 fold decrease) over the last few decades. Over the same time the use of these globes has risen significantly (about 9 fold increase).

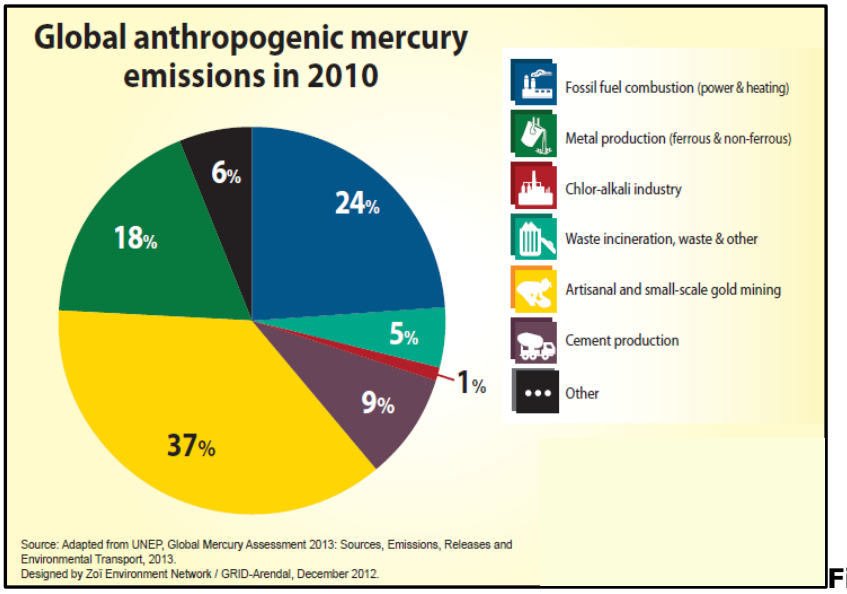

Figure 4 Sources and their Contributions to Mercury Emissions (UNEP 2013b)

2.5 Mercury in Coal

Coal is a combustible, sedimentary, organic rock composed mainly of carbon, hydrogen and oxygen. It is formed from prehistoric vegetation that has been subject to high pressure and temperature over millions of years. Mercury would have been present at low levels in the prehistoric vegetation. Mercury would also have been present in the sediments, soils and rocks in which the vegetation was buried. Over time the vegetation transforms to peat then into coal. The impurities present in the vegetation and in the surrounding materials stay with the coal as it forms and are carried through as the coal is mined and burnt in coal fired power generators.

Consequently, when coal is burned at a power plant the trace levels of mercury present in coal are released and potentially emitted to air (via the stack).

Mercury concentrations in Australian coals have been studied by the CSIRO. **Table 1** presents a summary of the mercury levels reported in the CSIRO study (CSIRO 2011).

Table 1 Mercury concentrations in Australian Coals and other materials (CSIRO 2011)

Type of Material	Concentration of Mercury (mg mercury per kg coal)
Australian Export Coals	0.01-0.08 (average 0.02)
Other internationally traded coals	0.01-0.19 (average 0.06)
Earth's crust	0.08
Shales	0.5

The US Geological Survey studied the concentration of mercury found in US coals. **Figure 5** presents a summary of the levels reported (note that concentrations in mg per kg are equivalent to concentrations in parts per million). From **Figure 5** it can be seen that many US coals have higher mercury concentrations than those in Australia. The US Geological Survey found that the average mercury concentration in a wide range of US coals was 0.17 ppm (mg/kg) compared to the CSIRO reported average of 0.02 mg/kg (USGS 2001).

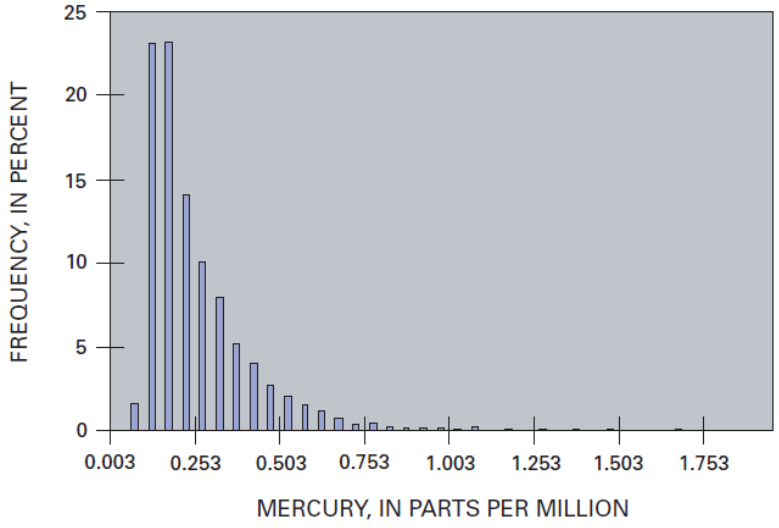

Figure 5 Concentration of Mercury in US Coals (USGS 2001)

2.6 Mercury Emissions in Australia

2.6.1 Emissions from All Sources

The National Pollutant Inventory (NPI) is the Australian system for looking at sources/emissions of a range of chemicals. Relevant industries are required to report on their use and release of a range of chemicals including mercury. Government generates estimates of releases from more diffuse sources. All of this information is then made available in the NPI database (NPI 2013).

The sources that released 100 kg per year or more to the atmosphere in the 2011-2012 reporting period include (in order of size of emission):

- paved/unpaved roads
- basic non-ferrous metal manufacturing (non-steel making)
- burning/wildfires
- electricity generation
- metal ore mining
- windblown dust
- basic ferrous meal manufacturing (steel making)
- coal mining
- cement, lime, plaster and concrete production

The diffuse sources included in this list are paved/unpaved roads, burning/wildfires, and windblown dust. Emissions from these sources are based on estimation techniques based on limited information. These emissions were estimated when the NPI commenced operations in 1998/99 and have not been revised since.

The paved/unpaved roads category covers the dust generated from the road surface as vehicles drive over it. For paved roads its dust from the particles in the exhaust of the vehicles, other sources of particles in the airshed as well as windblown dust while on unpaved roads the dust is from the road surface being pulverised as the vehicles drive across. As discussed, dust contains mercury and other metals and the emissions of mercury in this category are estimated using an assumption about how much mercury is in the dust (not based on measurements) along with the kilometres travelled by vehicles in Australia (NPI 1999a). Hence the estimates provided for these emission sources are not considered to be very reliable.

Table 2 presents a summary of mercury emissions to air from the top point source categories over the 7 year period to 2011/12. The emission estimates provided by these industries vary between years based on the level of activity at each facility. The level of activity may be impacted by the health of the local, national or global economy, demand for the product or service, technological issues or a range of other factors. The level of activity can affects whether companies report their emissions. Companies are required to report their emissions if they exceed activity thresholds. Hence when a company is close to the threshold, there are some years when they are required to report their emissions and there are other years when they are not required to report (NPI 2013). Hence the highly variable emissions available from the NPI only provides a mechanism for identifying the major sources of mercury emissions, but is not considered a reliable indicator of actual total emissions.

The major source of mercury emissions is basic non-ferrous metal manufacturing which includes primary smelting and refining; secondary metal processing and alloy production; solder production; and welding rod manufacture. Electricity generation and metal ore mining are the next largest point sources. For all of the listed categories, mercury emissions are unintentional releases from the extraction or use of natural materials including coal, mineral ores, calcium based materials (NPI 2013).

Table 2 Summary of Mercury Emissions to Air in Australia by Source (NPI 2013)

Category	Mercury Emission for Reporting Period in NPI (kg/year)						
	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12
Basic Non-Ferrous Metal Manufacturing	9 300	8 800	8 700	9 900	7 300	6 800	7 000
Electricity Generation	1 300	1 200	890	920	740	680	2 200
Metal Ore Mining	1 500	1 300	1 100	680	620	1 100	510
Basic Ferrous Metal Manufacturing	810	750	690	100	220	350	240
Coal Mining	87	99	98	120	94	120	130
Cement, Lime, Plaster and Concrete Production	340	190	150	120	120	190	150

More specifically in the Hunter Region, the following data is available from the NPI in relation to mercury emissions to air in 2011/2012. The table presents point sources that contribute more than 1 kg of mercury per year into the airshed.

Table 3 Summary of Mercury Emissions in Hunter River Airshed by Source (NPI 2013)

Source	Mercury Emission (kg/year)
Electricity generation*	93
Basic Ferrous Metal Manufacturing	44
Coal mining	30
Basic Non-Ferrous Metal Manufacturing	6.6
Ceramic Product Manufacture	1.9
Petroleum and Coal Product Manufacturing	1.9

*Sources listed are Bayswater Power Station, Liddell Power Station and Redbank Power.

Based on the data presented above, within the Hunter airshed, electricity generation is the largest source of mercury emissions to air (from industries required to report mercury emissions).

2.6.2 Emissions from Coal Fired Power Generators

Mercury emissions from CFPGs are a function of the concentration of mercury in coal and the emissions control equipment fitted to the facility.

Where only electricity generators are considered in Australia, the following data is available for 2011/2012 on the NPI database (NPI 2013) for point source emissions that are associated with the

combustion of coal for sources that produce more than 0.1 kg mercury per year. **Table 4** also presents the method of emission estimation provided in the NPI database.

Table 4 Summary of Mercury Emissions For CFPGs in Australia Reported in NPI Database 2011/12 (NPI 2013)

Name of Power Generating Facility	Location (suburb)	Mercury Emissions Reported (kg/year)***	Method Adopted for Estimating Mercury Emissions			
			Mass Balance	Engineering Calculations	Direct Measurement	Emission Factors
New South Wales						
Liddell Power Station	Muswellbrook	49		Y		Y
Eraring Power Station	Eraring	45.76			Y	
Bayswater Power Station	Muswellbrook	43.39		Y		Y
Wallerawang Power Station	Wallerawang	12		Y		
Mount Piper Power Station	Portland	9			Y	
Vales Point Power Station	Mannering Park	5.6 (22.4**)			Y	
Redbank Power	Warkworth	0.37			Y	
Victoria						
Loy Yang B Power Station	Traralgon	372				Y
AGL Loy Yang	Traralgon	197.9			Y	
Energy Brix Aust Corp P/L	Morwell	59.9				Y
Alcoa Anglesea Power Station	Anglesea	24.3			Y	
Energy Business Australia P/L	Cobram	0.46				Y
Yallourn Power Station*	Yallourn	460				
Hazelwood Power Station*	Hazelwood	450				
Leongatha Steam Company P/L	Leongatha	0.36				Y
Queensland						
Callide Power Plant	Biloela	104.6				Y
Callide Power Station (A & B)	Biloela	89.3				Y
Gladstone Power Station	Gladstone	72.5			Y	Y
Stanwell Power Station	Gracemere	39.1			Y	Y
Tarong Power Station	Nanango	25.3	Y			Y
Tarong North Power Station	Nanango	19.99				Y
Kogan Creek Power Station	Brigalow	14.1				Y
Swanbank (A & B) Power Station	Raceview	8.4				Y
Townsville Power Station	Yabulu	0.73				Y
Mica Creek Power Station	Mount Isa	0.63				Y
Millmerran Power	Millmerran	0.155				Y
Western Australia						
Muja Power Station	Collie	56.9				Y
Collie Power Station	Collie	42.5				Y
Bluewaters Power Station No 1&2	Palmer	17.5			Y	
Kwinana Power Station	Naval Base	14.7				Y
Newgen Power Kwinana Partnership	Naval Base	0.4				Y
Kwinana Cogeneration Plant	Kwinana Beach	0.13				Y
KMK Cogeneration Plant	Kwinana Beach	0.104			Y	
Tasmania						
Tamar Valley Power Station	Bell Bay	1.6				Y
South Australia						
Torrens Island Power Station	Torrens Island	2.94				Y
Osborne Cogeneration Plant	Osborne	1.3				Y
Northern Power Station	Port Augusta	0.1		Y	Y	
Northern Territory						
McArthur River Mine Power Station	Borroloola	0.15				Y

* Information provided by NGF

** 2011/12 data for Vales Point Power Station was reported incorrectly to NPI. Correct value provided by NGF.

*** These results are mostly estimated using emission factors. There is uncertainty in such estimates. An upper estimate of the uncertainty is +/- 50%.

The CFPGs that have reported the highest emission rates of mercury are located in the Latrobe Valley airshed in Victoria (includes Traralgon and Morwell) and the Hunter and Central Coast airsheds in New South Wales (includes Muswellbrook, Eraring, Wallerawang and Warkworth).

The methods by which CFPGs estimate mercury emissions from their facilities varies significantly. Most utilise emission factors to calculate emissions from their facility. A smaller number have estimated their emissions on the basis of direct measurements (i.e. measurements of mercury in stack emissions). Calculation of mercury emissions is undertaken based on NPI guidance (NPI 2012) that allows for these different emission estimation techniques. Calculations based on emission factors utilise factors derived from US, European and Australian sources. It is preferred that facility-specific data (monitoring data – i.e. direct measurement) is used to estimate emissions, however where this is not available emission factors can be used. Emission factors are available for the combustion of black coal, brown coal as follows:

- Black coal: Facility-specific emission factors are provided for mercury emissions for some facilities in NSW (Mt Piper, Vales Point and Wallerawang), Queensland (Tarong) and Western Australia (Collie, Muja and Kwinana). For other sites the emission factor is derived from the US EPA.
- Brown coal: Factors are available that are relevant to the combustion of Victorian brown coal (based on typical Australian measurements). For other brown coal a general emission factor for mercury is sourced from the US EPA.

Based on the above, it is noted that emissions estimated on the basis of direct measurements are considered more reliable, while those based on emission factors may be less reliable. Where facility or coal source specific data is available the emission estimates may be considered reasonably reliable, however for other facilities where general factors that come from the US EPA are considered these are less reliable as they are not likely to be based on mercury data for Australian coal (which is lower than in US coal).

Section 3. Potential for Exposure to Mercury

3.1 Overview

This section aims to provide an overview of the potential for exposure to mercury emissions from CFPGs located within the Hunter Valley/Central Coast airshed. It is noted that there are a number of CFPGs located in Australia with the more significant CFPGs (more significant in terms of the magnitude of the mercury emissions or the number of CFPGs located in the same airshed) are located in the regional airsheds of the Hunter Valley/Central Coast in NSW and LaTrobe Valley in Victoria.

The airshed of the Hunter Valley/Central Coast has been selected for the purpose of conducting a preliminary assessment of potential exposures to mercury emissions from CFPGs. This is intended to provide an indication of whether the potential for exposure to mercury from these sources is likely to be significant and warrant more detailed quantification of emissions in other areas of Australia, or consideration of whether specific mercury abatement measures need to be considered.

The modelling of potential mercury emissions to air from the CFPGs in the Hunter Valley/Central Coast area has been undertaken by Todoroski Air Sciences (TAS). The TAS report is included in **Appendix A** (it should be consulted for detailed information on the modelling conducted) and has been summarised in the following sections of the report.

3.2 CFPGs in Hunter Valley Region

3.2.1 Locations

The CFPGs included in the study presented in this report include Vales Point and Eraring Power Stations located on the shores of Lake Macquarie in the Central Coast airshed and Bayswater and Liddell Power Stations in the upper Hunter Valley airshed (as illustrated in **Figure 6**, from TAS 2013).

The topography of the region (as illustrated in **Figure 7**) is characterised by a wide valley running from the northwest to southeast, bounded by the Barrington Tops National Park to the north and Wollemi National Park to the South. The geographical features of the valley play an important role in local wind patterns and potential exposures to emissions from CFPGs within the valley.

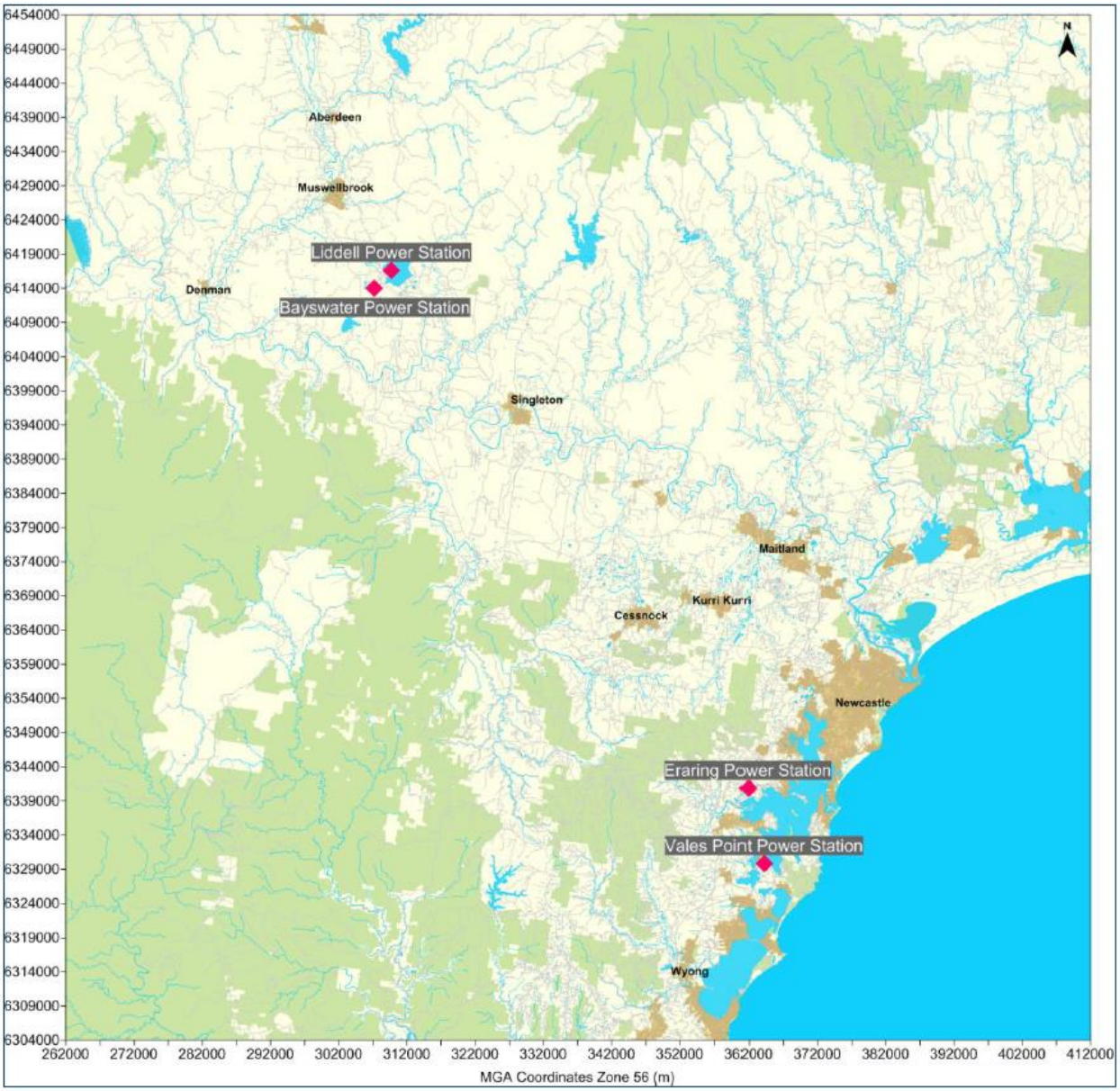

Figure 6 Location of CFPGs in Hunter Valley/Central Coast Area (from TAS 2013, refer to Appendix A)

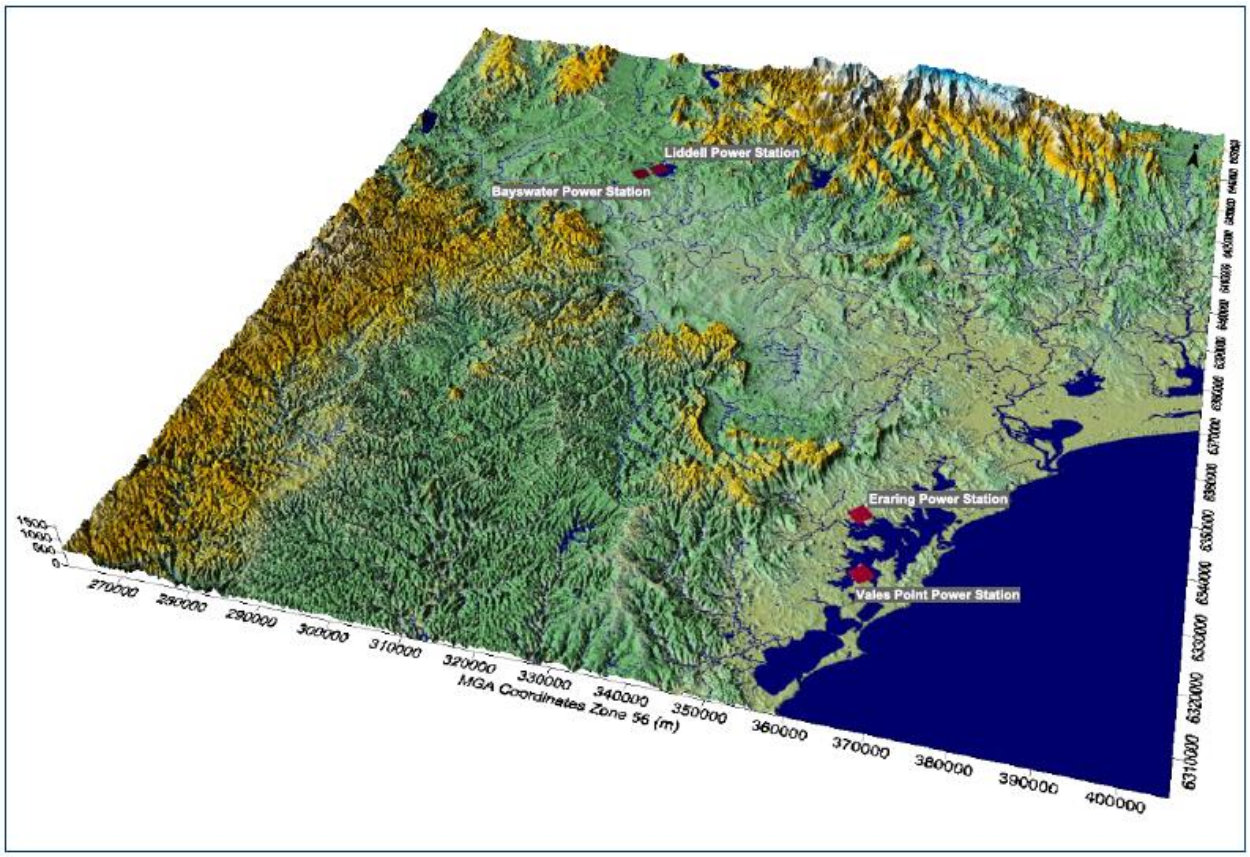

Figure 6 Topography of Hunter Valley/Central Coast Region (from TAS 2013, refer to Appendix A)

3.2.2 CFPGs Mercury Emission Sources

In relation to potential emissions of mercury from the operation of the CFPGs considered in this assessment, emissions data has been provided by each of the CFPGs. This data is based on stack test data available from each facility. It is noted that measurements of mercury in the stack test data are variable (with emission rates reported spanning an order of magnitude). The emission rate adopted in this assessment is an average measured emission rate which is relevant to the quantification of potential chronic exposures in the community where the long-term average level of exposure is the appropriate indicator.

The emission rate adopted in this assessment (based on measured data) has been compared with the mercury emissions reported in the NPI database (based on some measured data for Eraring and Vales Point but emission estimates using emission factors for Liddell and Bayswater). This comparison is shown in **Table 5**.

Table 5 Summary of Mercury Emissions to Air from CFPGs in Hunter Valley/Central Coast Area

Power Station	Mercury Emissions to Air Reported in NPI (kg/year)					Mercury Emissions to Air as Modelled from Data Provided by each CFPG (kg/year) (value in brackets is the emission rate in g/s as used in air model)
	2007/08	2008/09	2009/10	2010/11	2011/12	
Vales Point	71	120	36	27	5.6	35 (0.0011)
Eraring	78	47	42	43	46	57 (0.0018)
Liddell	95	63	54	45	49	9.5 (0.0003)
Bayswater	70	42	55	66	43	38 (0.0012)

Review of **Table 5** indicates that the emission rate adopted in this assessment for Vales Point, Eraring and Bayswater are reasonably consistent with average emissions reported in the NPI database. The measured emission rate for Liddell is lower than that reported in the NPI database. It is noted that emissions reported in the NPI database for Liddell are based on the use of emission factors (refer to **Table 4** and **Section 2.6.2**) that may have included the use of more generic US emission factors. This is expected to have overestimated potential emissions of mercury to air from the operation of the facility. While there are uncertainties in any stack measurement data, the use of measured data from Liddell in this assessment is considered to provide a more reliable estimation of mercury emissions than the NPI emission estimates.

The emissions to air from the CFPGs occur via the discharge stacks at each facility. The stack parameters considered in the modelling of emissions to air from these facilities are summarised in **Table 6**.

Table 6 Summary of Stack Parameters Considered in Mercury Emissions Model (refer to Appendix A)

Parameter	Power Station Considered in Assessment							
	Vales Point	Eraring		Liddell		Bayswater	
Number of stacks	1	2		2		2	
Stack Location	364347mE, 6329922mN	361986mE, 6340950mN	361958mE, 6340744mN	309825mE, 6416658mN	309802mE, 6416495mN	307314mE, 6413987mN	307057mE, 6414106mN
Stack Height	206 m	200 m		168 m		248 m	
Stack Tip Diameter	11m	10.47 m		10 m		12 m	
Exit Velocity	14.3 m/s	13.7 m/s		17.7 m/s		12.5 m/s	
Temperature	125 ^{o}C	100 ^{o}C		140 ^{o}C		125 ^{o}C	

3.3 Form of Mercury Released from CFPGs

3.3.1 General

When coal is burned in a power plant the small amounts of mercury present in coal are released. Within the power station, mercury that is present in coal will be volatilised to elemental mercury which is in a gaseous state ($Hg^0(g)$) in the high temperature furnace. As the flue gas is cooled some is oxidised to other mercury species including those adsorbed to the solid phase (Hg(s)). The formation of other mercury species from $Hg^0(g)$ will depend on the temperatures and presence of other gases and their concentrations. Hence mercury will be present in coal combustion flue gases primarily as $Hg^0(g)$ and gaseous or solid inorganic mercuric compounds like $Hg^{2+}X(g,s)$ where X is $Cl_2(g)$, $SO_4(s)$, O(s,g) and/or S(s). In more simple terms the emissions can be divided into 3 main forms: elemental $Hg^0(g)$; ionic $Hg^{2+}X(g)$ and solid or particulate Hg(s). The various speciation pathways for mercury from coal combustion are illustrated in **Figure 7**.

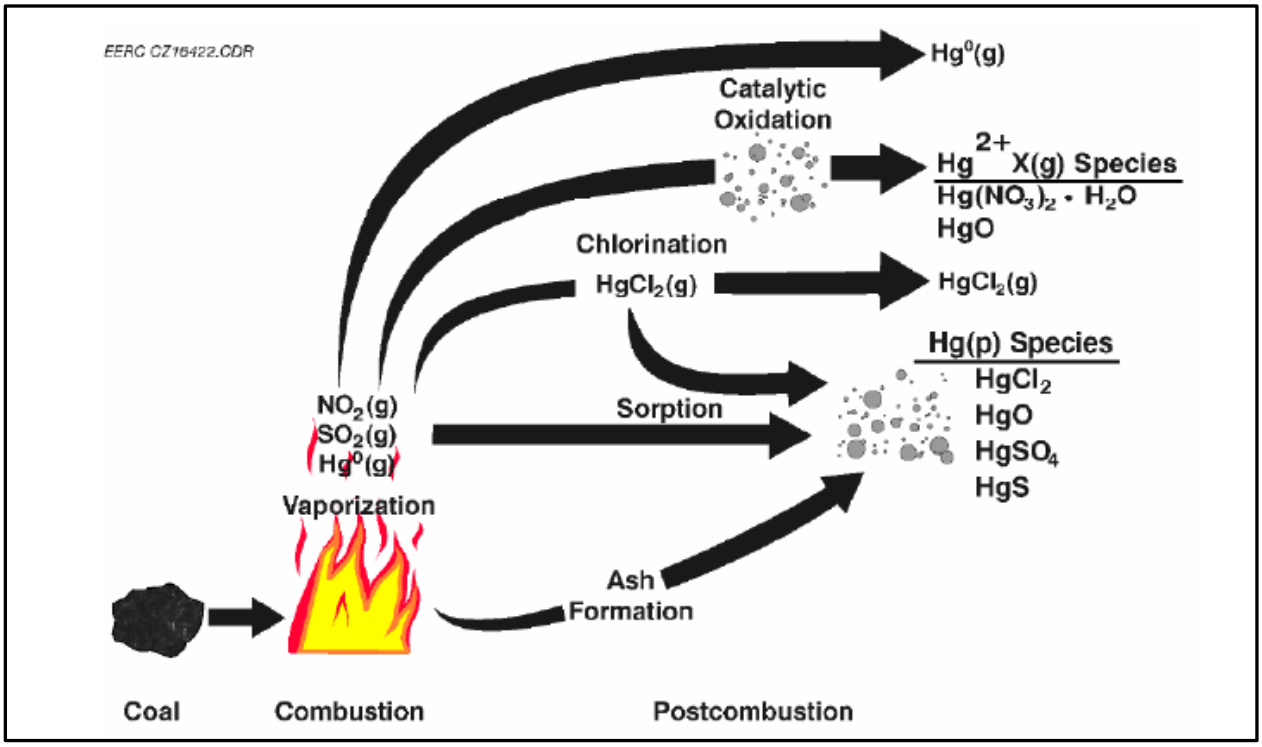

Figure 7 Potential Mercury Speciation Pathways from Coal Combustion (Newman-Sutherland et al. 2001)

Mercury released into the atmosphere in particulate form deposits via wet (rain) or dry (particulate/dust) deposition processes. The particles contain mercury mainly in the form of oxidised mercury or (Hg(II)). This oxidised mercury can be either direct deposition of emitted Hg(II) or from conversion of emitted elemental Hg^0 to Hg(II) through ozone-mediated reduction. The former process may result in elevated deposition rates of Hg(II) around atmospheric emission sources.

$Hg^0(g)$ is not susceptible to these major deposition processes due to its high vapour pressure, low water solubility and stability in the atmosphere. It cannot dissolve in the water vapour in the atmosphere and does not form particulates unless it reaches high levels in the atmosphere where ozone-mediated reduction can occur. Consequently, Hg^0 remains in the atmosphere for a long period of time with an average residence time in the atmosphere of about one year. This process results in regional/global transport followed by deposition when it eventually is converted into particles. Hence deposition from Hg^0 sources does not occur in the area located close to the source, rather these emissions contribute to more regional/global distribution of mercury. $Hg^0(g)$ is the primary species of background levels of mercury in the atmosphere.

In relation to the use of emissions control equipment, ionic $Hg^{2+}X(g)$ and solid or particulate Hg(s) are more effectively captured in conventional pollution control systems than $Hg^0(g)$ (Newman-Sutherland et al. 2001). Hence the emissions to air from the CFPGs considered in this assessment are more likely to be dominated by the presence of $Hg^0(g)$.

3.3.2 Potential for Deposition to be of Significance

It is expected that the majority of emissions to air from CFPGs will be in the form of $Hg^0(g)$ which will not readily deposit close to the emission sources. A more detailed evaluation of the potential for mercury emissions from three CFPGs in the United States to deposit in local soil or water bodies close to the emission sources (Sullivan et al. 2005) did not identify that this was a significant pathway. The available data did not show mercury deposition rates in local areas were different from background rates of mercury deposition.

On this basis, while some depositional processes are expected to occur in the region evaluated the contribution from the CFPG sources addressed in this report is not considered to be significant. The focus of this assessment will therefore relate to the inhalation of mercury in air within the regional areas evaluated.

3.4 Geographical Area

The CFPGs considered in this assessment are within the Hunter Valley and Central Coast airshed. These airsheds are dominated by the topography (as shown in **Figure 6**) and local/regional air movements within this area are dominated by the impact of these key features. The meteorological conditions in this region, as well as the basis for developing a meteorological data file to be used in the modelling of emissions from the CFPGs is presented in the TAS report included in **Appendix A**.

The area that comprises the Hunter Valley and Central Coast airshed includes a number of urban (residential/commercial/industrial) areas that include the major centre of Newcastle as well as a number of smaller and larger towns, and a number of rural properties. The whole region (set up on a grid basis) has been considered in the modelling of emissions from the CFPGs (refer to **Appendix A**). In addition, the key urban areas in the area have been identified as individual receptor locations for the characterisation of exposure in the modelling. These urban areas are illustrated in **Figure 8**.

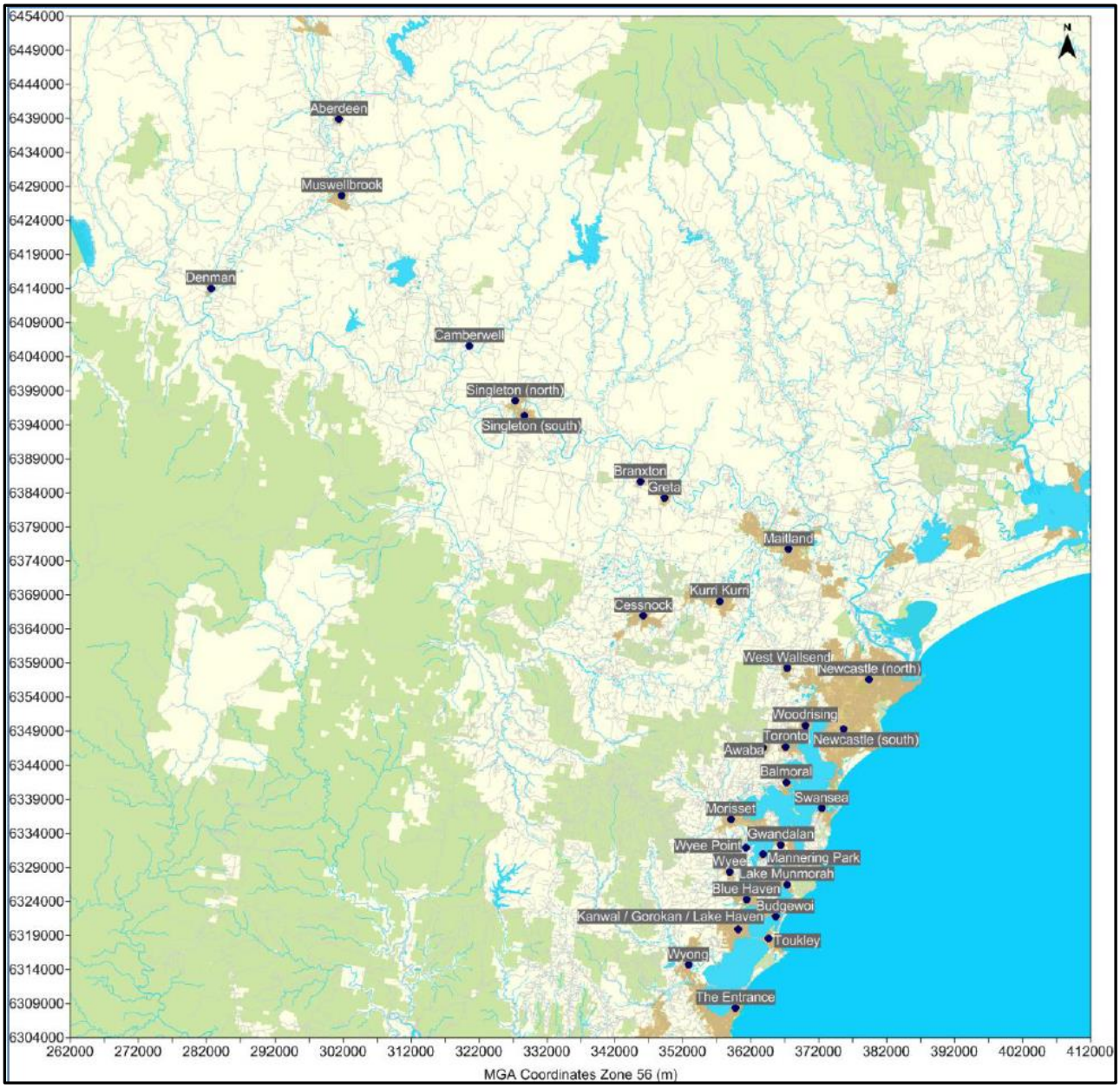

Figure 8 Urban Areas Considered in Hunter Valley/Central Coast Region (from TAS 2013, refer to Appendix A)

The population located within the Hunter Valley and Central Coast area are located within eleven local government areas (LGAs). **Table 7** presents a summary of the population in these LGAs based on census data collected in 2011. This table shows that the composition of the population in the various LGAs changes with some areas such as Gloucester and Great Lakes comprising an older population with a higher percentage of residents aged 70 years and over, while areas (particularly where they are located in mining related areas) such as Muswellbrook, Cessnock and Singleton comprise a younger population with a higher proportion of young children.

Table 7 Population in Area of Interest

Local Government Area	Population	Median Age	Children 0-9 years	Elderly 70 years and over
Cessnock	50,840	37	14.3%	9.5%
Dungog	8,318	44	11.9%	11.9%
Gloucester	4,877	50	10.2%	17.8%
Great Lakes	34,430	52	9.8%	21.8%
Lake Macquarie	189,006	41	12%	12.9%
Maitland	67,478	36	14.7%	8.8%
Muswellbrook	15,791	34	15.6%	7%
Newcastle City	148,535	37	11.7%	11.3%
Port Stephens	64,807	42	12.8%	12.9%
Singleton	22,694	35	14.6%	6.8%
Upper Hunter	13,754	39	14.4%	11.4%

3.5 Characterising Mercury Exposures in Hunter Valley/Central Coast Region

Emissions of mercury from the 4 CFPGs considered in the Hunter Valley and Central Coast area has been undertaken by TAS with the modelling report included in **Appendix A**. The modelling undertaken has considered the following:

- Terrain of the region;
- Meteorology relevant to the region (based on data available from 11 surface observation stations), relevant to 5 separate years, January 2007 to December 2011;
- Stack parameters and emission rates as outlined in **Section 3.2.2**;
- Consideration of impacts derived from each individual facility as well as the cumulative impacts associated with the operation of all 4 facilities in the region;
- Calculation of concentrations of mercury in air at points within a 150 x 150 m grid across the whole region;
- Calculation of ground level concentrations of mercury at each of the urban centres identified in the region (as illustrated in **Figure 8**).

The characterisation of mercury concentrations in air has focused on long-term averages (as an average over the 5 year period modelled as well as the maximum annual average from all the years considered in the model), consistent with the key health effects associated with the inhalation of mercury (refer to **Section 4**). As the quantification of potential concentrations in air has addressed a large region of NSW it is reasonable to assume that individuals may spend all day, every day of their lifetime either working or living within the region. Hence the calculated concentrations of mercury in air are considered representative of the long-term average concentrations the population may be exposed to (and inhale) for a lifetime.

The results of the modelling of mercury emissions from the CFPGs is presented in **Appendix A**, and further discussed and evaluated in **Section 5**.

3.6 Uncertainties

The largest uncertainty identified in the estimation of potential mercury exposures in the Hunter Valley/Central Coast region is the quantification of mercury emissions from each of the CFPGs considered. The measured concentrations of mercury in the stack test data provided varies by up to an order of magnitude. This data has been used to quantify long-term or chronic exposures to mercury in the region where use of an average measured emission rate is appropriate. It is noted that for each facility the number of stack tests conducted each year varies, with some facilities providing data from annual testing and others from quarterly testing. The available data is therefore limited and the average emission rate considered may not reflect a true annual average. These uncertainties have been further considered in **Section 5 and 6**.

Section 4. Toxicity of Mercury

4.1 Approach

The objective of the toxicity assessment is to identify toxicity values that can be used to quantify potential risks to human health associated with calculated intake. Toxicity can be defined as *"the quality or degree of being poisonous or harmful to plant, animal or human life"* (NEPC 1999b).

The objective of the toxicity review is to identify appropriate quantitative toxicity values for each chemical and pathway of exposure (oral, dermal or inhalation) that can be used to quantify risk. This has involved the following key steps:

1. Identify the relevant health end-points, and, where carcinogenicity is identified, the mechanism of action. This enables the identification of whether a threshold or non-threshold dose-response approach is appropriate; and
2. Identify the most appropriate quantitative value for the assessment of threshold or non-threshold effects. This includes consideration of susceptible populations, where relevant.

For chemicals that are not carcinogenic, a threshold exists below which there are no adverse effects (for all relevant end-points). The threshold typically adopted in risk calculations (using toxicity reference values [TRVs] such as acceptable/tolerable daily intake [ADI/TDI] or tolerable concentration [TC]) is based on the lowest no observed adverse effect level (NOAEL), typically from animal or human (e.g. occupational) studies, and the application of a number of safety or uncertainty factors. Intakes/exposures lower than the TRVs are considered "safe", or not associated with an adverse health risk (NHMRC 1999a).

Where the chemical has the potential for carcinogenic effects, the mechanism of action needs to be understood as this defines the most appropriate dose-response approach to be considered. Carcinogenic effects are associated with multi-step and multi-mechanism processes that may include genetic damage, altering gene expression and stimulating proliferation of transformed cells. Some carcinogens have the potential to result in genetic (DNA) damage (gene mutation, gene amplification, chromosomal rearrangement), and are termed genotoxic carcinogens. For these carcinogens it is assumed that any exposure may result in one mutation or one DNA damage event that is considered sufficient to initiate the process for the development of cancer sometime during a lifetime (NHMRC 1999a). Hence, no safe-dose or threshold is assumed (hence any exposure is associated with some level of incremental lifetime risk), and assessment of exposure is based on a linear or non-threshold approach using TRVs termed as slope factors or unit risk values.

For other (non-genotoxic) carcinogens, while some form of genetic damage (or altered cell growth) is still necessary for cancer to develop, it is not the primary mode of action for these chemicals. For these chemicals, carcinogenic effects are associated with indirect mechanisms (that do not directly interact with genetic material) where a threshold is believed to exist, and are characterised using threshold TRVs such as an ADI/TDI or a TC.

The US EPA (US EPA 2005) requires the mode of action for carcinogenicity to be clearly understood before accepting a threshold approach for assessing exposures to non-genotoxic carcinogens. Where data are lacking and the mechanism is poorly understood, the default is to adopt a non-threshold approach.

Current industry practice in Australia is to not simply default to a non-threshold approach where understanding (or data) is lacking (as in the US); rather, the approach is to provide an adequate review of available information to enable a decision to be made based on the weight of evidence (enHealth 2012a; NEPC 1999b). This approach has been adopted in this assessment.

4.2 Properties

Mercury is a heavy metal which exists in three oxidation states: 0 (elemental), +1 (mercurous) and +2 (mercuric). As well as the common mercurous and mercuric inorganic salts, mercury can also bind covalently to at least one carbon atom. Thus the most commonly encountered exposures associated with mercury are with elemental mercury, inorganic mercuric compounds and methylmercury.

Elemental mercury is a dense, silvery white metal which is liquid at room temperature, readily volatilises and is considered to be the predominant form of mercury in the atmosphere. Mercury compounds differ greatly in general properties and solubility. Due to the wide range in properties associated with the forms of mercury, key properties have not been listed here, however they are available in a number of published reviews (ATSDR 1999; WHO 2003).

4.3 Exposure

Exposure of the general population to mercury may occur via inhalation, oral or dermal contact. Exposure to elemental mercury may occur in the workplace or home if mercury is spilled and it is the most significant form likely to be present in ambient/background air. Inorganic mercury compounds are found in some batteries, pharmaceuticals, ointments and herbal medicines. Exposure to inorganic mercury can occur via inhalation, ingestion or dermal contact. Methylmercury is most commonly found in fish, especially larger fish at the top of the food chain with exposure typically associated with ingestion. The focus of this assessment relates primarily to the inhalation pathway, specifically to $Hg^0(g)$ and potentially some inorganic mercurous species.

As discussed in **Section 3.3.2**, the deposition pathway is not considered to be significant for the emission sources evaluated, and hence the potential for significant deposition to soil and aquatic environment and subsequent methylation is not considered to be significant. The focus of the information present in this section will therefore relate to the presence of elemental and inorganic mercury species in air.

Current literature indicates that mercury (Hg) in the environment exhibits complex behaviour that affects both its mobility and potential toxicity. Mercury has a low solubility in water; however, it also has the potential to form multiple species in the environment, which can lead to increased total mercury concentrations in aqueous systems. The relative toxicity of mercury is also dependent on the form in which it occurs which can be affected by biogeochemical processes; partitioning between solids, groundwater, and vapour; and complexation with dissolved organic and inorganic ligands.

On the basis of the potential for long-range transport, persistence in water, soil and sediment, bioaccumulation, toxicity and ecotoxicity, mercury is considered persistent and is addressed in the 1998 UN-ECE Convention on Long-Range Transboundary Air Pollution on Heavy Metals (UNECE 1998). The United Nations Environment Programme (UNEP) Governing Council concluded, at its 22nd session in February 2003, after considering the key findings of the first Global Mercury

Assessment report, that there is sufficient evidence of significant global adverse impacts from mercury to warrant further international action to reduce the risks to humans and wildlife from the release of mercury to the environment. The UN Governing Council decided that national, regional and global actions should be initiated as soon as possible and urged all countries to adopt goals and take actions, as appropriate, to identify populations at risk and to reduce human-generated releases.

4.4 Health Effects

The following information relevant to elemental and inorganic mercury is available from published evaluations (ATSDR 1999; EA 2009; WHO 2003). The focus of the information presented relates to the inhalation exposure pathway and hence less detailed information is presented in relation to other pathways such as ingestion and dermal absorption.

4.4.1 Elemental Mercury (Hg^0)

General

Limited data is available concerning the absorption of elemental mercury. In relation to exposure to elemental mercury the inhalation pathway is the most significant. Approximately 80% of mercury vapour inhaled by humans crosses the alveolar membranes into the blood.

Absorbed mercury is lipophilic and rapidly distributes to all tissues. It is able to cross the blood-brain and foetal barriers easily. Mercury is oxidised in the red blood cells by catalase and hydrogen peroxide to divalent ionic mercury. Approximately 7-14% of inhaled mercury vapour is exhaled within a week of exposure. The rest of the elemental mercury is either excreted via sweat and saliva, or is excreted as mercuric mercury. Approximately 80% is excreted as mercuric mercury via faeces and urine. Half-life elimination is approximately 58 days.

Acute exposure to high concentrations of mercury vapour has been associated with chest pains, haemoptysis, breathlessness, cough and impaired lung function with the lung identified as the main target following acute exposure.

The central nervous system is generally the most sensitive indicator of toxicity of metallic mercury vapour. Data on neurotoxic effects are available from many occupational studies.

Chronic exposure to metallic mercury may result in kidney damage with occupational studies indicating an increased prevalence of proteinuria.

Carcinogenicity and Genotoxicity

Both US EPA and IARC indicate that elemental mercury is not classifiable as to its human carcinogenicity. No adequate animal studies are available for elemental mercury and occupational studies have indicated conflicting results.

4.4.2 Inorganic Mercury Compounds

General

Limited data is available concerning the absorption of inhaled mercury compounds; however it is expected to be determined by the size and solubility of the particles. Absorption of ingested inorganic mercury has been estimated to be approximately 5 to 10% with absorption by children greater than for adults.

Inorganic mercury compounds are rapidly distributed to all tissues following absorption. The fraction that crosses the blood-brain and foetal barriers is less than for elemental mercury due to poor lipid solubility. The major site of systemic deposition of inorganic mercury is the kidney. Most inorganic mercury is excreted in the urine or faeces.

Acute exposure to high concentrations of ingestion of inorganic mercury has been associated with gastrointestinal damage, cardiovascular damage, acute renal failure and shock.

The kidney is the critical organ associated with chronic exposure to inorganic mercury compounds. The mechanism for the end toxic effect on the kidney, namely autoimmune glomerulonephritis, is the same for inorganic mercury compounds and elemental mercury and results in a condition sometimes known as nephrotic syndrome.

There is some evidence that inorganic mercury may cause neurological effects, particularly associated with studies of mercuric chloride. Reproductive and developmental effects have been observed in rats given mercuric chloride.

Carcinogenicity and Genotoxicity

IARC considers inorganic mercury compounds not classifiable as to human carcinogenicity. The US EPA has classified mercuric chloride as a possible human carcinogen (Class C) based on increased incidence of squamous cell papillomas of the forestomach and marginally increased incidence of thyroid follicular cell adenomas and carcinomas from a long term oral studies in rats.

Carcinogenicity studies in experimental animals are available on mercuric chloride only where no carcinogenic effect was observed in mice or female rats, while marginal increases in the incidence of thyroid follicular adenomas and carcinomas and forestomach papillomas were observed in male rats exposed orally. Mercuric chloride binds to DNA and induces clastogenic effects *in vitro*; *in vivo*, where both positive and negative results have been reported, without a clear-cut explanation of the discrepancy. The overall weight of evidence is that mercuric chloride possesses weak genotoxic activity but does not cause point mutations (WHO 2011). The IRIS (US EPA) evaluation of mercuric chloride indicates that a linear low-dose extrapolation is not appropriate as kidney tumour seen in mice occurred at doses that were also nephrotoxic. On this basis, in accordance with enHealth (2012) guidance, it is not considered appropriate that a non-threshold dose-response approach be adopted for the assessment of mercuric chloride.

4.5 Quantitative Toxicity Values

4.5.1 General

Review of toxicological studies and risk assessments by several countries and international organisations have established levels of daily or weekly intakes of mercury that are estimated to be "safe" (refer to the WHO review (UNEP 2008)). That is, there is a threshold or reference level below which exposures/intakes are not associated with adverse effects. The WHO makes it clear in their assessment that these reference levels are not a clear dividing line between safe and unsafe. This is because they have incorporated a number of safety/uncertainty factors into their calculation of the reference level for mercury which means a slight exceedance of this value does not immediately result in adverse effects.

4.5.2 Elemental and Inorganic Mercury

On the basis of the available information in relation to elemental and inorganic mercury a threshold approach is considered appropriate based on the most sensitive effect associated with chronic mercury exposure. The following threshold values are available for the assessment of inhalation exposures from Level 1 Australian and international sources:

Table 8 Toxicity Reference Values for Inhalation of Inorganic and Elemental Mercury

Source	Value	Basis/Comments
WHO (WHO 2000)	TC = 0.001 mg/m^3	Tolerable concentration (TC) or guideline value derived on the basis of a LOAEL derived from occupational studies on elemental vapour. The WHO notes that "since cationic inorganic mercury is retained only half as much as the vapour, the guideline also protects against mild renal effects caused by cationic inorganic mercury". "Present knowledge suggests, however, that effects of the immune system at lower exposures cannot be excluded". On this basis the TC derived and presented in this evaluation is not considered to be adequately protective of adverse health effects for all members of the population.
WHO (WHO 2003)	**TC = 0.0002 mg/m^3**	A TC in air was also derived for elemental mercury in air (0.0002 mg/m^3) associated with a LOAEL associated with CNS effects in workers exposed to elemental mercury. The evaluation provides a revision of the limited TC presented in the WHO (2000) and is considered to be more robust and suitable for the quantification of chronic health risks associated with exposure to all forms of mercury in air.
UK (EA 2009)	TC = 0.0002 mg/m^3	Inhalation value (converted to a dose by the UK) based on the WHO (2003) value assumed to be relevant to inorganic mercury in air.
Dutch (Baars et al. 2001; RIVM 2000)	TC = 0.0002 mg/m^3	TC derived on the same basis as ATSDR and WHO (2003).
United States (ATSDR 1999)	Inh. MRL = 0.0002 mg/m^3	The chronic inhalation MRL for elemental mercury based on a LOAEL (HEC) of 0.0062 mg/m^3 associated with CNS effects in workers and an uncertainty factor of 30. The value derived is consistent with that derived by the WHO (2003)
United States IRIS (US EPA)	RfC = 0.0003 mg/m^3	RfC (last reviewed in 1995) for elemental mercury based on a LOAEL (HEC) of 0.009 mg/m^3 associated with CNS effects in workers and an uncertainty factor of 30. A subchronic RfC is also available from HEAST (1995), which is equal to the chronic RfC.

Inhalation values for elemental mercury are derived from occupational studies associated with elemental mercury vapour. The more current review provided by WHO (2003) is consistent with that adopted by UK (EA 2009), Dutch (Baars et al. 2001; RIVM 2000) RIVM (2001) and US (ATSDR

1999; US EPA), and has been adopted for the assessment of inhalation exposures to elemental mercury.

4.6 Background Exposure/Intake

Background intakes of elemental mercury (dominant species considered in this assessment) have also been considered to ensure that the total intake of elemental mercury from background sources as well as the CFPGs does not exceed the adopted TC. Exposures to elemental mercury may be derived from background air (from a range of sources, excluding CFPGs) and dental amalgams. In relation to these sources the following is noted:

- Review (NHMRC 1999b) of intakes associated with amalgam fillings in Australian children and adults (based on average number of fillings of 0.5 and 8 respectively) provides an reasonable estimate of daily mercury absorption per person of about 0.3 µg for children and 3.5 µg for adults. The estimate for children is expected to be conservative as the use of mercury dental amalgams is declining.
- Levels of inorganic mercury in air are not available for Australia with estimates in the US reported (WHO 2003) for mercury in air ranging from 10 to 20 ng/m^3 (0.01-0.02 µg/m^3) (no indication on speciation between elemental and inorganic).

Based on the above data, these intakes/exposures may comprise up to 10% of the adopted inhalation TRV.

4.7 Summary

The following provides a summary of the TRVs adopted for the assessment of potential inhalation exposures to mercury (as primarily elemental mercury) as well as relevant assumptions in relation to the proportion of the total intake that may occur from sources other than contamination (i.e. air, dental fillings).

Elemental Mercury:
Inhalation TRV (TRV_I) = 0.0002 mg/m^3 or 0.2 µg/m^3 (WHO 2003) – relevant to the inhalation pathway only (other pathways not of significance for this form of mercury) for chronic exposures.
Background intakes from other sources (as % of TRV) = 10% or 0.02 µg/m^3
Absorption = 100% absorbed into the body following inhalation

Section 5. Characterisation of Risk

5.1 Approach

Risk characterisation is the final step in a quantitative risk assessment. It involves the incorporation of the exposure and toxicity assessment to provide a quantitative evaluation of risk. Risk is characterised separately for threshold and non-threshold carcinogenic effects. In relation to the assessment of potential risks associated with exposure to mercury (elemental and potentially inorganic forms) only threshold effects are relevant. Hence no non-threshold risk is calculated in this assessment.

Risks can be defined to be "acceptable" or tolerable if the exposed public could be expected to bear them without undue concern. Risks may be considered to be unacceptable if they exceed a specified regulatory limit, or if the circumstances are such that the risks cannot be accepted. Negligible risks are those that are so small that there is no cause for concern about them, or so unlikely that there is no reason to take action to reduce them.

Perceptions of risk are also important in determining whether risks from contamination in particular locations can be considered tolerable. The risks that tend to be of greatest concern are those that are involuntary (such as contamination from industry or industrial emissions), man-made and perceived as potentially catastrophic in their consequences.

The process of risk assessment aims to assist risk managers in addressing the potential impact of a proposed development or an existing or possibly foreseeable future situation on the surrounding community and the communication of the potential risks.

Assessment of Threshold Effects

The quantification of potential exposure and risks to human health associated with the presence of chemicals where a threshold dose-response approach is appropriate has been undertaken by comparing the estimated intake (or exposure concentration) with the threshold values adopted that represent a tolerable intake (or concentration), with consideration for background intakes[1]. The calculated ratio is termed a Hazard or Risk Index (HI/RI), which is the sum of all ratios (termed Hazard or Risk Quotients [HQ/RQ]) over all relevant pathways of exposure. For the quantification of inhalation exposures this is calculated on the basis of the following equation (USEPA 2009):

$$Hazard\,/\,Risk\;\;Quotient\,[HQ\,/\,RQ](inhalation) = \frac{Exposure\,Concentration\,in\,Air}{TRV - Background}$$

More specifically in this assessment of mercury exposures in air, the following equation has been used:

$$RQ(inhalation) = \frac{Predicted\,Concentration\,of\;Hg\;in\;Air\,(\mu g/m^3)}{TRV\,(0.2\,\mu g/m^3) - Background(0.02\,\mu g/m^3)}$$

[1] Background intakes are intakes of a chemical that are derived from sources other than the contamination being assessed (refer to **Section 4.6**).

The interpretation of an acceptable RQ needs to recognise an inherent degree of conservatism that is built into the establishment of appropriate TRV adopted (using many uncertainty factors) and the exposure assessment. Hence, in reviewing and interpreting the calculated RQ the following is noted:

- A RQ less than or equal to a value of 1 (where intake or exposure is less than or equal to the threshold) represents no cause for concern (as per risk assessment industry practice, supported by published guidance and protocols (enHealth 2012a; NEPC 1999b; USEPA 2009));
- A RQ greater than 1 requires further consideration within the context of the assessment undertaken, particularly with respect to the level of conservatism in the assumptions adopted for the quantification of exposure and the level of uncertainty within the toxicity (threshold) values adopted.

5.2 Quantification of Exposure and Risk

The modelling of mercury concentrations in air by TAS (refer to **Appendix A**) has calculated long-term average concentrations in air for each individual power station and for all 4 facilities operating together, based on all years of modelling (5-years) and the maximum 1 year period.

It is noted that in this assessment the exposure concentration considered in the calculation of a relevant RQ is equal to the modelled concentration in air as the population is assumed to be exposed to the predicted concentrations all day, every day for a lifetime while working and residing in the region evaluated.

Figures 9 and 10 present contours of the predicted 5-year average (**Figure 9**) and maximum 1-year average (**Figure 10**) concentrations of mercury from all four CFPGs operating in the Hunter Valley and Central Coast region evaluated. The contours illustrate that the maximum concentrations of mercury predicted in the region considered are located closest to the individual CFPGs. The cumulative impacts in areas away from the CFPGs are low.

Table 9 presents a summary of the calculated cumulative 5-year average and maximum 1-year average concentrations of mercury at each of the key urban locations considered as well as the maximum concentration predicted in the whole region. Based on these predicted concentrations and the toxicity values presented in **Section 4**, a RQ has been calculated at each location. The calculated RQ is also presented in **Table 9**. It is noted that the air concentrations and calculated RQs have been presented to 2 significant figures.

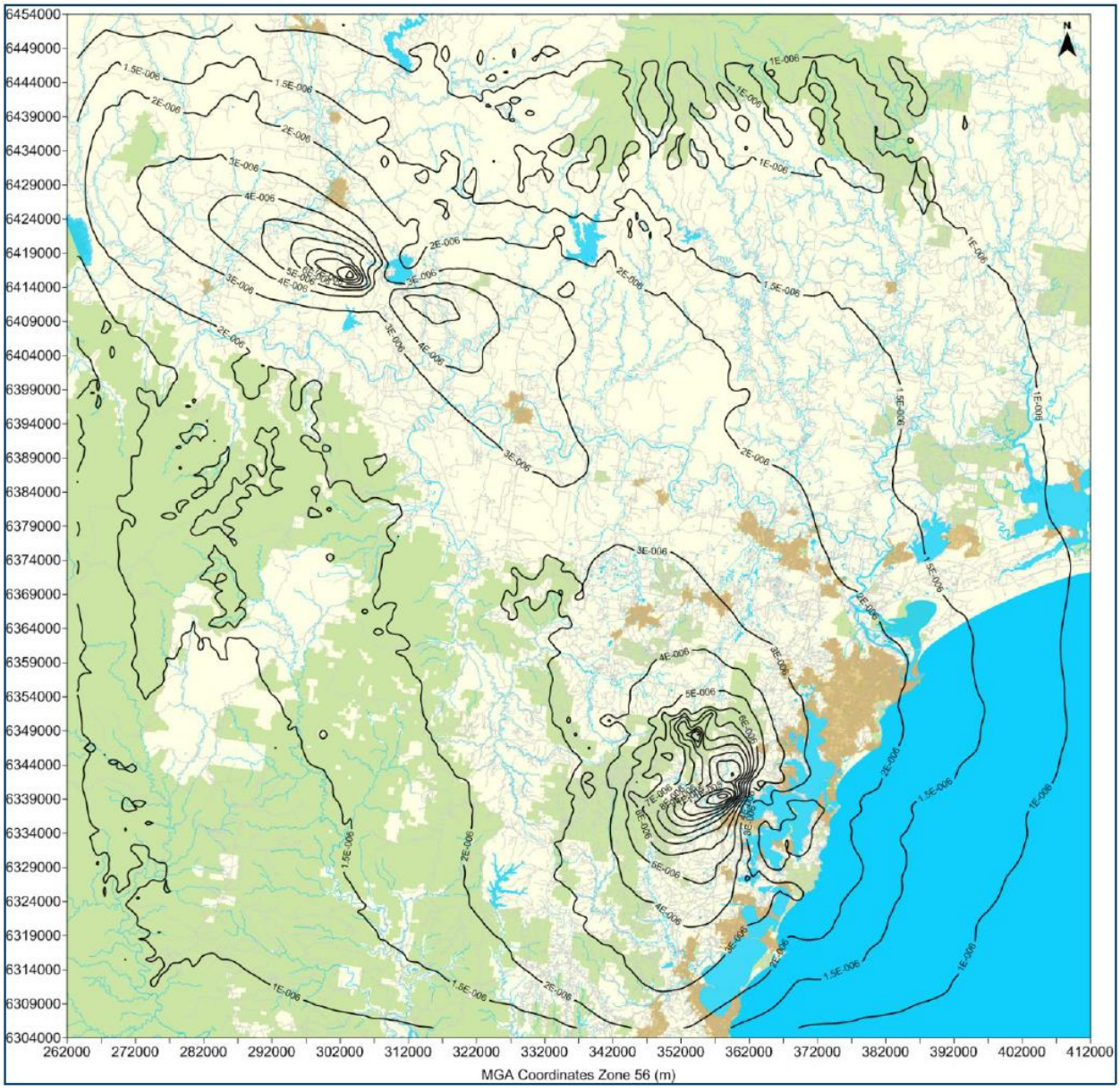

Figure 9 Cumulative 5-year average Mercury Concentrations (2007-2011) (µg/m^3) (from TAS, refer to Appendix A)

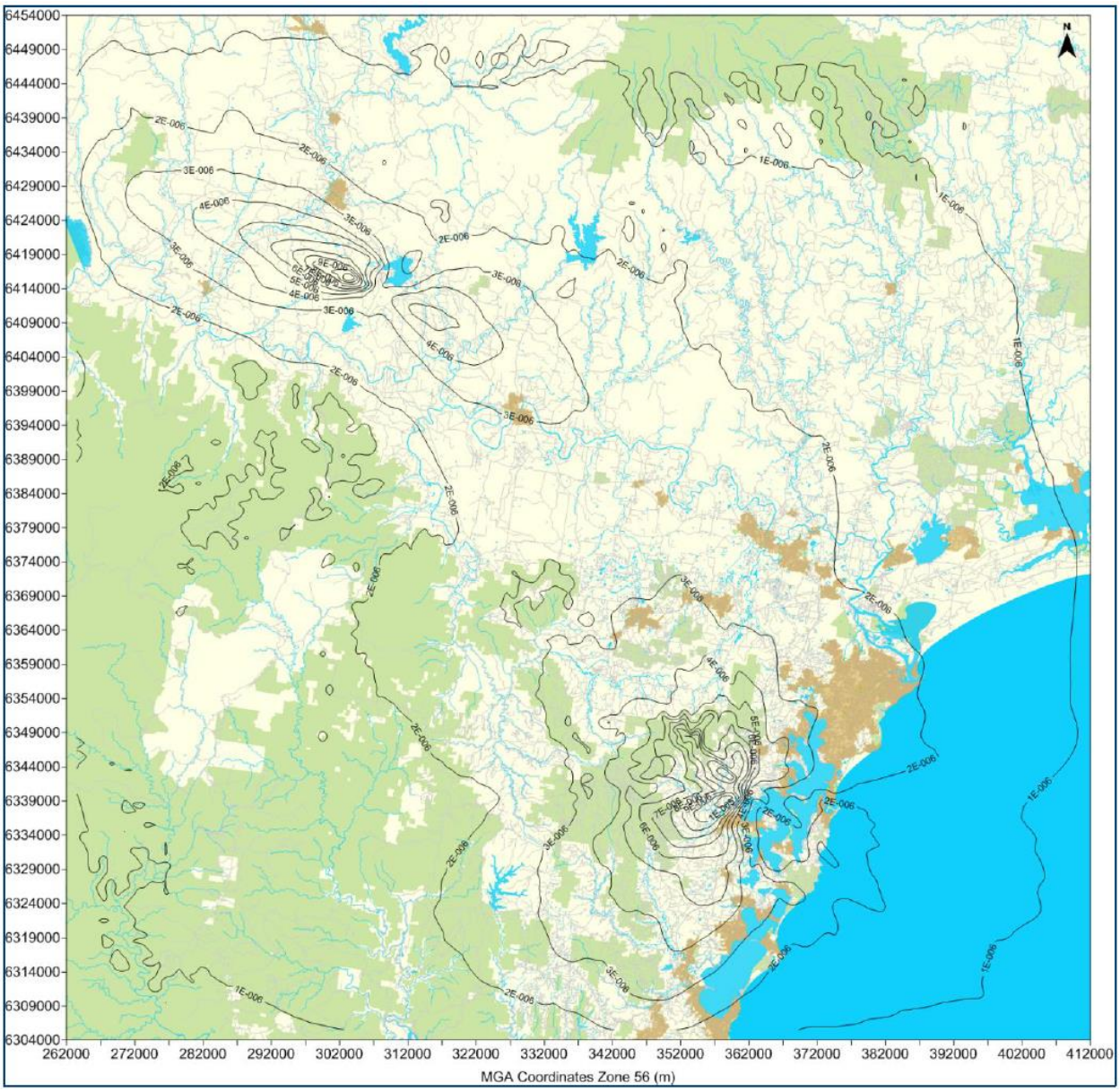

Figure 9 Cumulative Maximum 1-year average Mercury Concentrations (2007) (µg/m^3) (from TAS, refer to Appendix A)

Table 9 Summary of Cumulative Mercury Concentrations in Air and Calculated RQs in Urban Areas and Maximum in Region

Location	Evaluation Based on 5-Year Average Concentrations		Evaluation Based on Maximum 1-Year Average Concentrations (2007)	
	Cumulative Concentration of Hg in Air (μg/m^3)	Calculated Risk Quotient (RQ)	Cumulative Concentration of Hg in Air (μg/m^3)	Calculated Risk Quotient (RQ)
The Entrance	0.0000019	0.000011	0.0000027	0.000015
Wyong	0.0000033	0.000019	0.0000047	0.000026
Toukley	0.0000025	0.000014	0.0000035	0.000019
Kanwal / Gorokan / Lake Haven	0.0000031	0.000017	0.0000047	0.000026
Lake Munmorah	0.0000032	0.000018	0.0000049	0.000027
Wyee	0.0000047	0.000026	0.0000068	0.000038
Budgewoi	0.0000026	0.000014	0.0000039	0.000022
Blue Haven	0.0000034	0.000019	0.0000054	0.000030
Mannering Park	0.0000022	0.000012	0.0000033	0.000018
Wyee Point	0.0000035	0.000019	0.0000049	0.000027
Morisset	0.0000063	0.000035	0.0000070	0.000039
Gwandalan	0.0000019	0.000011	0.0000026	0.000014
Balmoral	0.0000039	0.000021	0.0000043	0.000024
Swansea	0.0000019	0.000011	0.0000029	0.000016
Newcastle (south)	0.0000025	0.000014	0.0000039	0.000022
Newcastle (north)	0.0000023	0.000013	0.0000038	0.000021
Toronto	0.0000038	0.000021	0.0000052	0.000029
Woodrising	0.0000030	0.000017	0.0000044	0.000024
Awaba	0.0000056	0.000031	0.0000062	0.000035
West Wallsend	0.0000029	0.000016	0.0000041	0.000023
Cessnock	0.0000035	0.000019	0.0000046	0.000025
Kurri Kurri	0.0000030	0.000017	0.0000044	0.000024
Maitland	0.0000023	0.000013	0.0000043	0.000024
Greta	0.0000027	0.000015	0.0000049	0.000027
Branxton	0.0000028	0.000016	0.0000051	0.000028
Singleton (south)	0.0000033	0.000018	0.0000062	0.000034
Singleton (north)	0.0000034	0.000019	0.0000066	0.000037
Muswellbrook	0.0000027	0.000015	0.0000064	0.000036
Aberdeen	0.0000016	0.0000091	0.0000033	0.000018
Denman	0.0000026	0.000014	0.0000056	0.000031
Camberwell	0.0000043	0.000024	0.000010	0.000056
Max level in domain	**0.0000060**	**0.000033**	**0.000012**	**0.000066**
RQ adopted as indicative of acceptable risks		**≤1**		**≤1**

Review of the calculations presented in **Table 9** indicates that the RQ is significantly lower than 1 at all locations, indicating that there are no adverse effects associated with potential exposures of the community in the Hunter Valley and Central Coast to mercury that may be derived from the operation of the four CFPGs located within that airshed.

The margin of safety (MOS) is more than 10 000 fold. It is noted in **Section 3.6** that the mercury emission rates considered in this assessment are variable and that due to the limitations with the available data there is some uncertainty in relation to the values adopted. However, the emission rates of mercury from the CFPGs would need to be significantly higher (more than 10 000 times higher) for potential exposures by the community to be considered of potential concern. The variability reported in the stack testing data is in the order of 10 fold. Hence while there is some

uncertainty in the available data it is not sufficient to be of concern or impact the conclusions presented in this report.

In relation to other CFPGs in Australia, while mercury emissions reported in the NPI database for power stations located in the LaTrobe Valley in Victoria are higher than those considered in the Hunter Valley and Central Coast region (refer to **Table 4**), the emission rates from those CFPGs are not more than 10 000 times higher than considered in this assessment.

Based on the assessment undertaken, human health impacts associated with mercury emissions that may be derived from the operation of CFPGs in Australia are considered to be negligible and do not warrant more detailed quantification or management.

Section 6. Conclusions

This report has presented a preliminary desk-top study to quantify potential chronic health risks associated with emissions of mercury to air from coal-fired power generators (CFPG). The presence of mercury in emissions from CFPGs relates to the presence of trace levels of mercury in coal. In Australia there are a number of CFPGs with a wide range of power generating capacity and potential for mercury emissions. To evaluate the potential for mercury emissions to be of concern to the health of local/regional populations this assessment has focused on assessing potential emissions and exposures derived from the operation of four CFPGs in the Hunter Valley and Central Coast airshed of NSW.

Based on the assessment undertaken and within consideration of the uncertainties identified the following can be concluded:

- No adverse health effects are associated with potential exposures by the community in the Hunter Valley and Central Coast to mercury that may be derived from the operation of the four CFPGs located within that airshed.
- In relation to other CFPGs in Australia, while mercury emissions reported in the NPI database for power stations located in the LaTrobe Valley in Victoria are higher than those considered in the Hunter Valley and Central Coast region, the emission rates from those CFPGs are not high enough to be of concern as there is a significant margin of safety (more than 10 000 fold) in the assessment undertaken (i.e. emissions would have to be more than 10 000 times higher to result in concentrations higher than the guideline).

While there is some uncertainty in the measurement and modelling in the estimates of mercury concentrations in air, it is of the order of 10 fold. As noted the margin of safety (MOS) is more than 10 000 fold. Hence while there is some uncertainty in the available data it is not sufficient to be of concern, require further data to be collected or impact the conclusions presented in this report.

Given this margin of safety, the conclusions of this risk assessment are applicable throughout Australia in locations where CFPGs are present.

On this basis human health impacts associated with mercury emissions that may be derived from the operation of CFPGs in Australia are considered to be negligible and do not warrant more detailed quantification or management.

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Appendix A Todoroski Air Sciences - Air Modelling Study

AIR MODELLING STUDY

COAL FIRED POWER GENERATORS

HUNTER VALLEY REGION

Environmental Risk Sciences Pty Ltd

13th May 2013

Job Number 12040083

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Air Modelling Study
Coal Fired Power Generator
Hunter Valley Region

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1 INTRODUCTION

Todoroski Air Sciences has prepared this report for Environmental Risk Sciences Pty Ltd. It provides an air modelling study to establish typical ground level average mercury concentrations in the Hunter Valley region.

This report incorporates the following aspects:

- A general background to the Project;
- A description of the modelling approach and emission estimation;
- Presentation of the predicted results; and
- Discussion on the findings of this study.

This report is not intended for presentation to the community or regulator. It presents a very brief overview of what was done in predicting the likely levels of mercury that may arise from the power stations and also to present the results in a form suitable for use in a health risk impact assessment.

2 PROJECT BACKGROUND

This study focuses on mercury emissions emitted from major existing coal fired generators operating in the Hunter Valley region and the subsequent mercury exposure level at a selection of population centres within the region.

The coal fired generators assessed in this study include the Vales Point and Eraring Power Stations located on the shores of Lake Macquarie in the Central Coast and the Bayswater and Liddell Power Stations located in the upper Hunter Valley. The location of each of these coal fired generators is shown in **Figure 2-1**.

Figure 2-2 presents the topography of the study area. The topography of the study area is characterised by the Hunter Valley region defined by the mountainous features of the Barrington Tops National Park to the north and the Wollemi National Park to the south. The geographical features of the valley play a significant role in determining the local wind distribution patterns, which are apparent as a northwest or southeast flow along the valley.

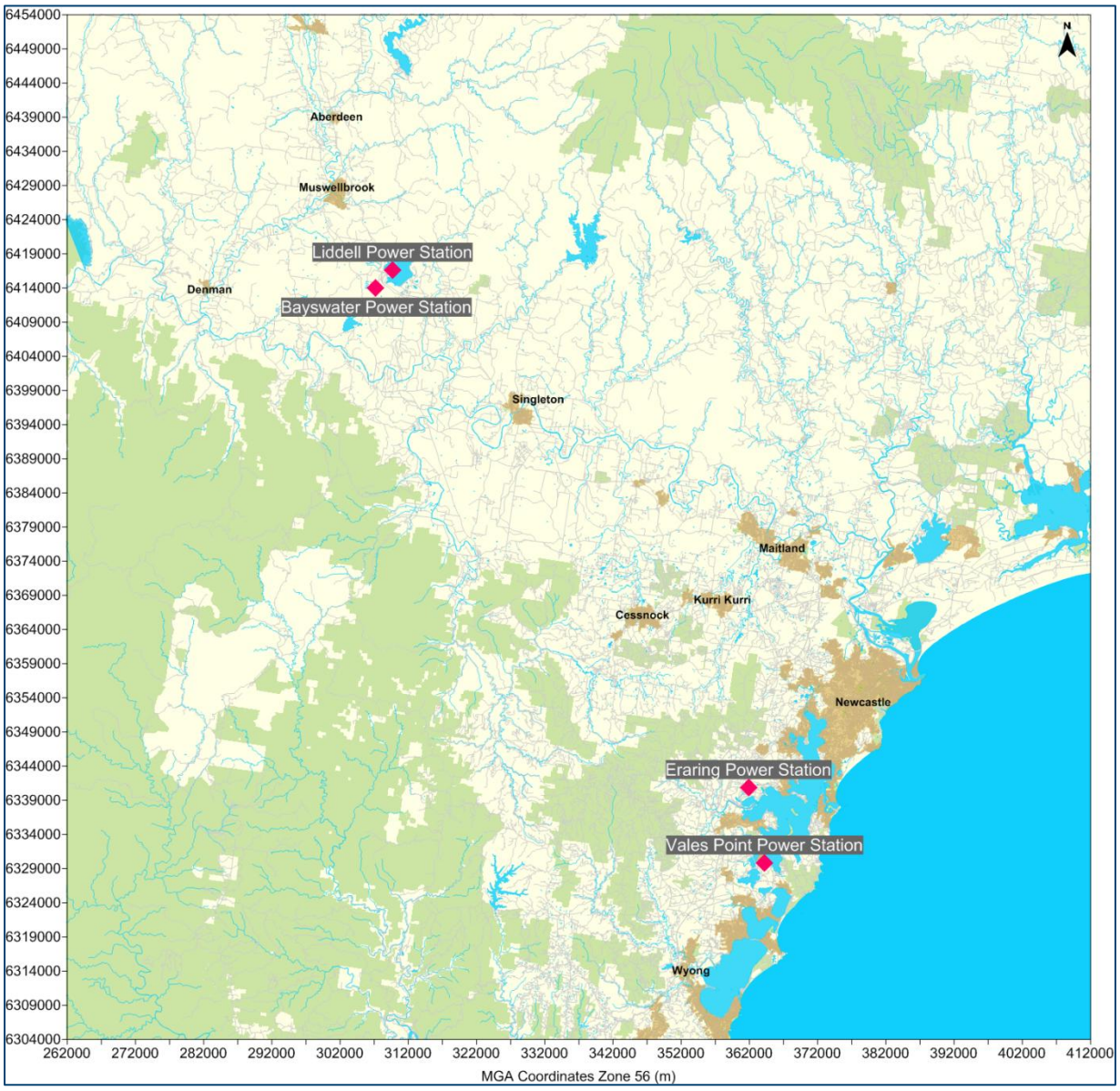

Figure 2-1: Modelling domain and source locations

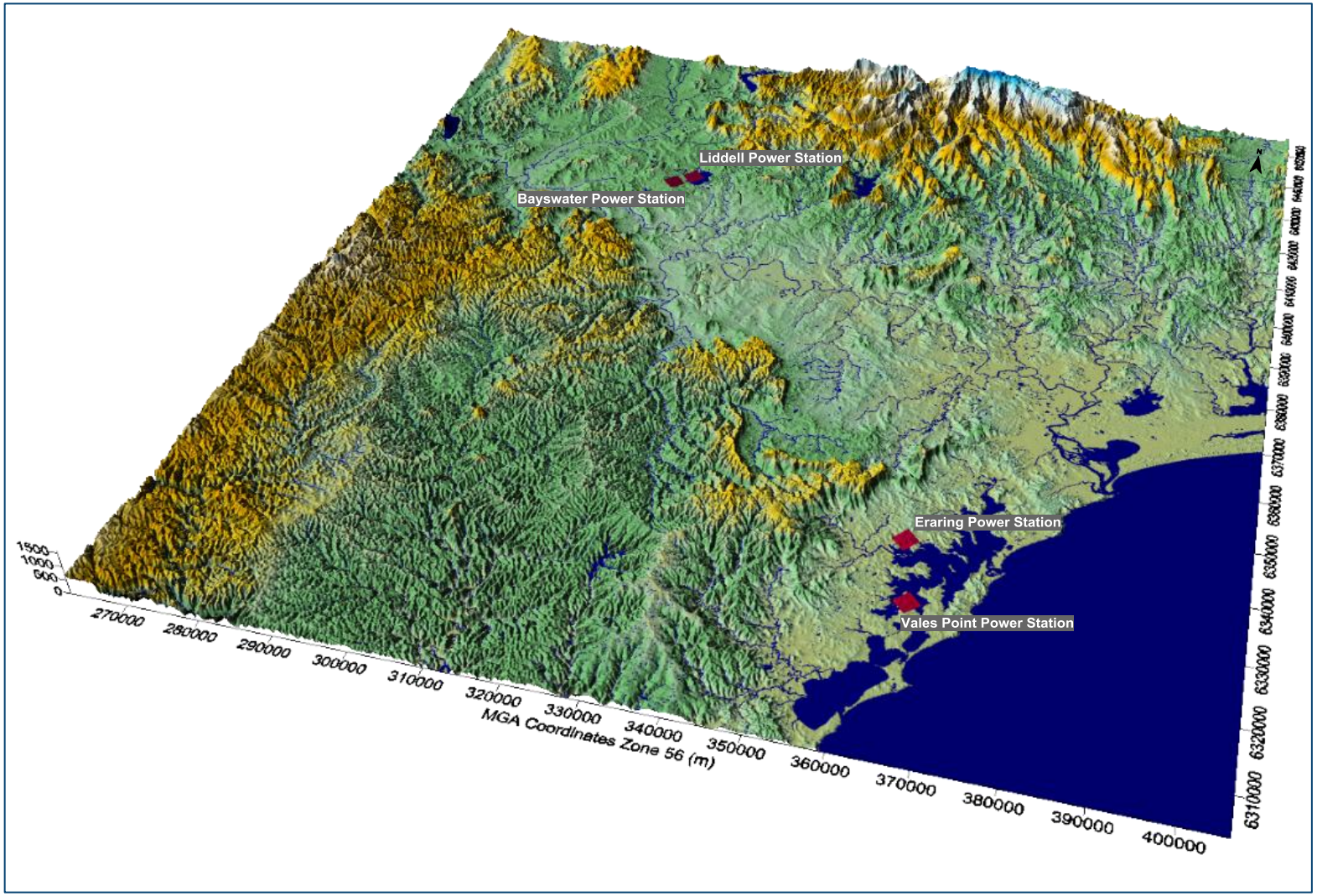

Figure 2-2: Topography of modelling domain

3 LOCAL CLIMATIC CONDITIONS

Long-term climatic data from the Bureau of Meteorology weathers stations at Jerrys Plains Post Office (Site No. 061086) and Norah Head Lighthouse (Site No. 061273) are used to characterise the local climate in the proximity of the coal fired generators assessed in this study.

Table 3-1 and **Figure 3-1** present a summary of data from Jerrys Plains Post Office (Jerrys Plains) collected over an approximate 125-year period. **Table 3-2** and **Figure 3-2** present a summary of data from Norah Head Lighthouse (Norah Head) collected over an approximate 30-year period.

The data indicate that January is the hottest month at Jerrys Plains with a mean maximum temperature of 31.7ºC and February is the hottest month at Norah Head with a mean maximum temperature of 25.1ºC. July is the coldest month with mean minimum temperatures of 3.8ºC and 9.3ºC respectively at Jerrys Plains and Norah Head.

Humidity levels exhibit variability and seasonal flux across the year. Mean 9am humidity levels range from 59% in October to 80% in June at Jerrys Plains and 70% in September to 83% in February at Norah Head. Mean 3pm humidity levels vary from 42% in the months of October, November and December to 54% in June at Jerrys Plains. Mean 3pm humidity levels at Norah Head vary from 63% in August to 77% in February.

Rainfall peaks during the summer months and declines during winter at Jerrys Plains whereas at Norah Head rainfall peaks during the first half of the year and declines in the second half of the year. The data indicates that January is the wettest month at Jerrys Plains with an average rainfall of 76.8mm over 7.9 days; February is the wettest month at Norah Head with an average rainfall of 142mm over 9.2 days. August is the driest month at both stations with an average rainfall of 36.3mm over 7.0 days and 70.7mm over 6.6 days respectively at Jerrys Plains and Norah Head.

As expected, wind speeds during the warmer months have a greater spread between the 9am and 3pm conditions compared to the colder months. At Jerrys Plains, mean 9am wind speeds range from 8.6km/h in April to 11.7km/h in September and mean 3pm wind speeds range from 11.0km/h in May to 14.7km/h in September. At Norah Head, mean 9am wind speeds range from 12.9km/h in July to 16.1km/h in February and mean 3pm wind speeds range from 16.7km/h in July to 23.5km/h in November.

Table 3-1: Monthly climate statistics summary - Jerrys Plains

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature												
Mean max. temperature (ºC)	31.7	30.9	28.9	25.3	21.3	18.0	17.4	19.4	22.9	26.2	29.1	31.2
Mean min. temperature (ºC)	17.2	17.1	15.0	11.0	7.4	5.3	3.8	4.4	7.0	10.3	13.2	15.7
Rainfall												
Rainfall (mm)	76.8	72.8	58.8	44.3	40.7	48.1	43.6	36.3	41.8	52.2	61.1	67.9
Mean No. of rain days (≥1mm)	7.9	7.5	7.5	6.4	6.6	7.7	7.2	7.0	6.6	7.6	7.7	7.7
9am conditions												
Mean temperature (ºC)	23.4	22.7	21.2	18.0	13.6	10.6	9.4	11.4	15.3	19.0	21.1	23.0
Mean relative humidity (%)	67	72	72	72	77	80	78	71	65	59	60	61
Mean wind speed (km/h)	9.6	9.0	8.8	8.6	9.0	9.4	10.6	11.0	11.7	10.9	10.5	9.9
3pm conditions												
Mean temperature (ºC)	29.8	28.9	27.2	24.1	20.1	17.1	16.4	18.2	21.2	24.2	26.9	29.0
Mean relative humidity (%)	47	50	49	49	52	54	51	45	43	42	42	42
Mean wind speed (km/h)	13.2	13.0	12.4	11.3	11.0	11.5	13.0	14.3	14.7	14.1	14.2	14.2

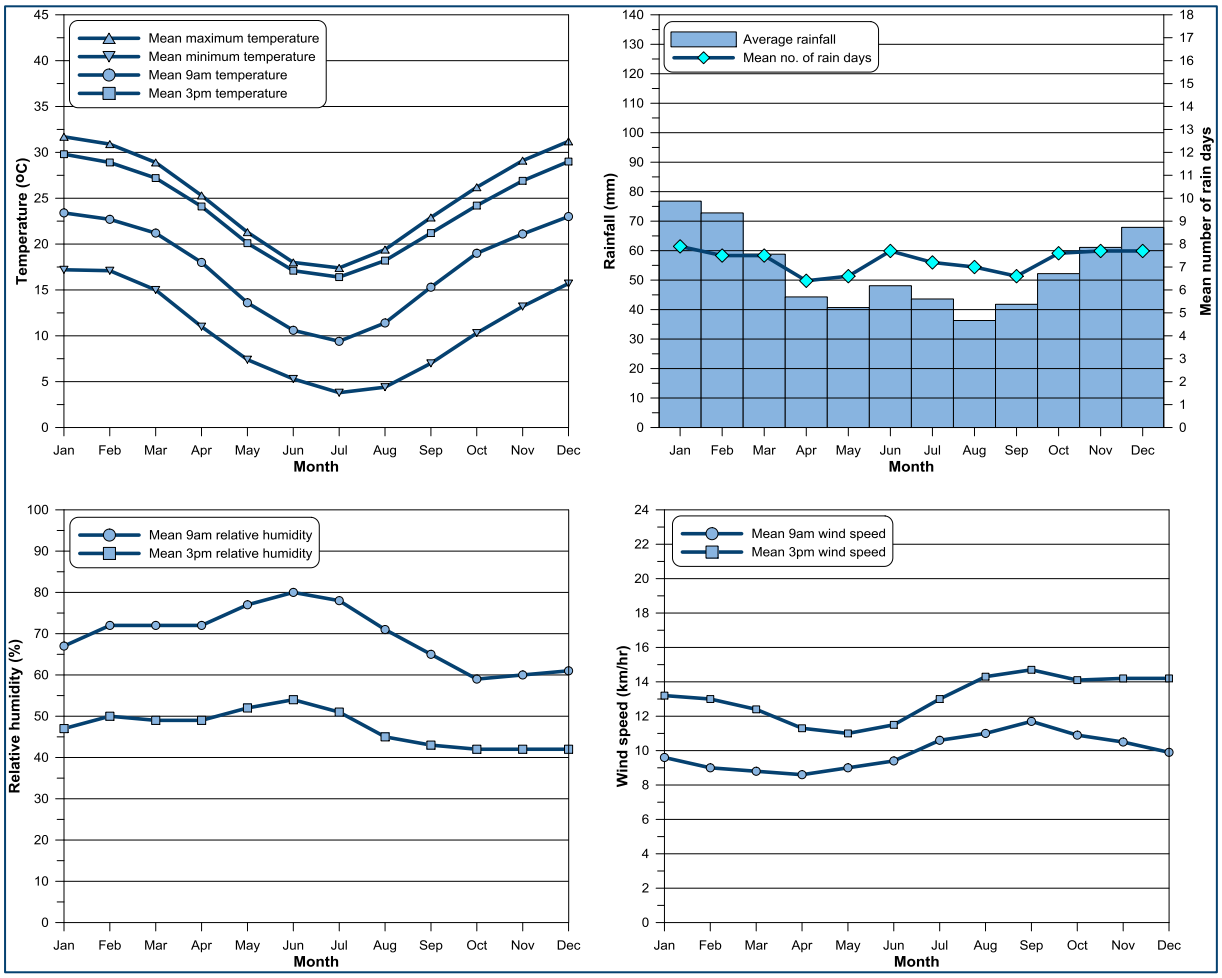

Figure 3-1: Monthly climate statistics summary - Jerrys Plains Post Office

Table 3-2: Monthly climate statistics summary - Norah Head Lighthouse

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature												
Mean max. temperature (ºC)	25.0	25.1	24.3	22.6	20.1	17.8	17.3	18.5	20.2	21.7	22.5	24.7
Mean min. temperature (ºC)	19.2	19.5	18.3	15.7	12.8	10.2	9.3	9.9	11.9	14.2	15.9	18.2
Rainfall												
Rainfall (mm)	106.4	142.0	129.0	118.1	132.3	126.5	80.4	70.7	75.1	76.9	96.5	80.6
Mean No. of rain days (≥1mm)	12.2	11.9	13.0	11.1	13.0	11.3	10.0	9.1	9.9	11.1	12.7	10.7
9am conditions												
Mean temperature (ºC)	22.0	22.1	21.3	19.3	16.0	13.3	12.4	13.8	16.4	18.5	19.3	21.4
Mean relative humidity (%)	81	83	80	78	79	77	76	72	70	72	76	78
Mean wind speed (km/h)	15.4	16.1	14.7	13.3	13.2	13.9	12.9	13.1	13.8	15.4	15.6	15.2
3pm conditions												
Mean temperature (ºC)	23.7	23.8	22.9	21.2	18.8	16.6	16.2	17.1	18.4	19.5	20.9	23.0
Mean relative humidity (%)	76	77	75	73	71	67	65	63	64	70	73	73
Mean wind speed (km/h)	22.9	22.5	21.1	19.8	17.4	17.8	16.7	19.3	22.2	22.8	23.5	23.2

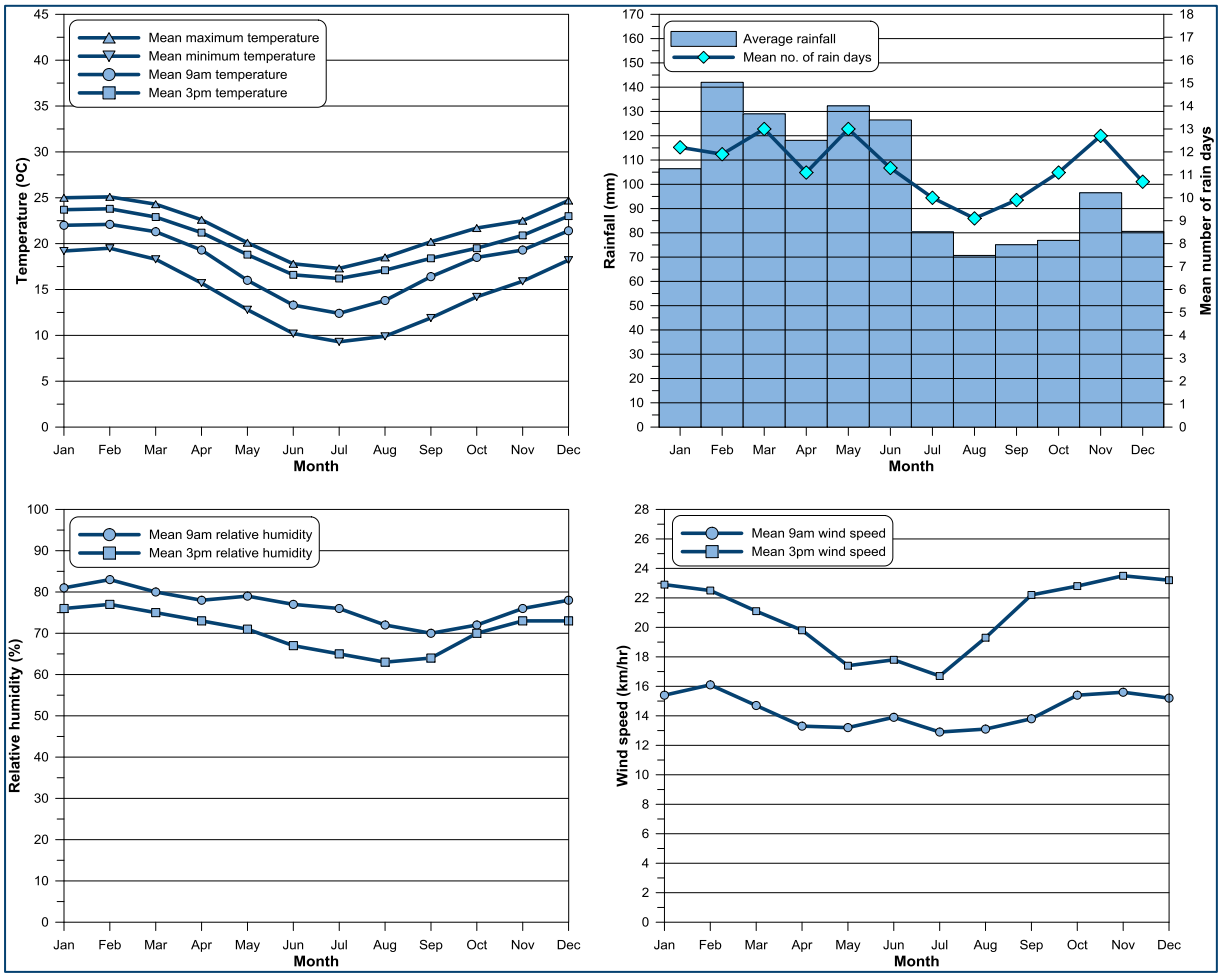

Figure 3-2: Monthly climate statistics summary - Norah Head Lighthouse

4 DISPERSION MODELLING APPROACH

4.1 Introduction

The dispersion model applied in this assessment is the CALPUFF model, an advanced "puff" model that can deal with the effects of complex local terrain on the dispersion meteorology over the entire modelling domain in a three dimensional (3D), hourly varying time step.

CALPUFF is an air dispersion model approved by NSW EPA for use in air quality impact assessments. The model setup is in general accordance with methods provided in the NSW EPA document "*Generic Guidance and Optimum Model Setting for the CALPUFF Modeling System for Inclusion into the 'Approved Methods for the Modeling and Assessments of Air Pollutants in NSW, Australia*'" (**TRC, 2011**).

4.2 Meteorological Modelling

TAPM and CALMET have been used to generate the 3D meteorological data field for the local region.

The centre of analysis for the TAPM modelling used is 32°42.5′ south and 151°15.5′ east. The simulation involved three nesting grids of 30km, 10km and 3km with 35 vertical grid levels.

CALMET modelling used observed surface wind field data from 11 surface observation stations outlined in **Table 3-1** in conjunction with upper air data generated from TAPM. The CALMET modelling grid domain was run on a 150 x 150km domain with a 1km grid resolution.

Table 4-1: Surface observation data used in the modelling

Station	Parameters
Williamtown RAAF (BoM Station No. 061078)	WS, WD, CH, CC, Temp, RH and SLP
Murrurundi Gap AWS (BoM Station No. 061392)	WS, WD, CH, CC, Temp, RH and SLP
Merriwa (Roscommon) (BoM Station No. 061287)	WS, WD, CH, CC, Temp, RH and SLP
Nullo Mountain AWS (BoM Station No. 062100)	WS, WD, Temp and RH
Scone Airport AWS (BoM Station No. 061363)	WS, WD, Temp, RH and SLP
Paterson (Tocal AWS) (BoM Station No. 061250)	WS, WD, Temp and RH
Cessnock Airport AWS (BoM Station No. 061260)	WS, WD, Temp, RH and SLP
Newcastle Nobbys Signal Station AWS (BoM Station No. 061055)	WS, WD, Temp and RH
Cooranbong (Lake Macquarie AWS) (BoM Station No. 061412)	WS, WD, Temp, RH and SLP
Gosford (Narara Research Station) (BoM Station No. 061087)	WS, WD, Temp and RH
Mangrove Mountain AWS (BoM Station No. 061375)	WS, WD, Temp and RH

Local land use and detailed topographical information were included to produce realistic fine scale flow fields (such as terrain forced flows) in the modelling domain.

The meteorological modelling was conducted over a five year period from January 2007 to December 2011.

4.3 Dispersion Modelling

The modelling sources included the exhaust stacks from each of the coal fired generators. The modelling parameters for each of the sources are summarised in **Table 4-2**.

Table 4-2: Modelled stack parameters

Parameter	Vales Point	Eraring		Liddell		Bayswater	
No. of stacks	1	2		2		2	
Stack location	364347mE, 6329922mN	361986mE, 6340950mN	361958mE, 6340744mN	309825mE, 6416658mN	309802mE, 6416495mN	307314mE, 6413987mN	307057mE, 6414106mN
Stack height	206m	200m		168m		248m	
Stack tip diameter	11m	10.47m		10m		12m	
Exit velocity	14.3m/s	13.7m/s		17.7m/s		12.5m/s	
Temperature	125ºC	100ºC		140ºC		125ºC	

4.3.1 Emission estimation

Emission estimates of mercury from each of the coal fired generators are based on the average result obtained from a number of site specific stack testing events. The emission rates used in the modelling are summarised in **Table 4-3**.

Table 4-3: Modelled emission rate

Source	Emission rate	Units
Vales Point	0.0011	g/s
Eraring	0.0018	g/s
Liddell	0.0003	g/s
Bayswater	0.0012	g/s

5 DISPERSION MODELLING RESULTS

Dispersion model predictions are presented in tabular format for a selection of urban areas (see **Figure 5-1**) and also as isopleth diagrams for the five year annual average cumulative and incremental scenarios and the maximum year for both cumulative and incremental (see **Figure 5-2** to **Figure 5-11**).

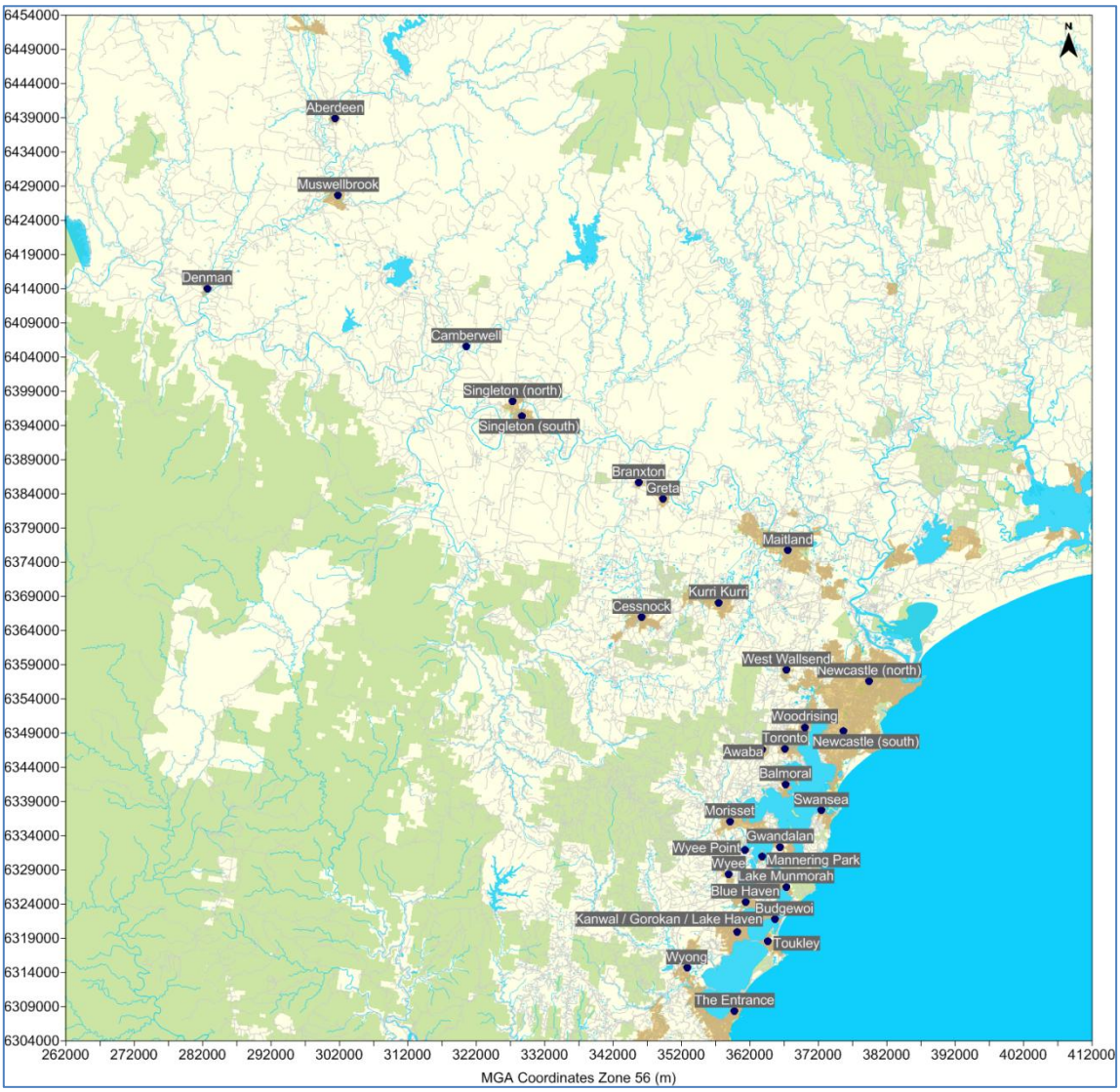

Figure 5-1: Urban areas in the assessment

Table 5-1 presents the discrete predictions at each of the urban areas selected for the five year annual average cumulative and incremental scenarios.

Table 5-2 presents the discrete predictions at each of the urban areas selected for the maximum year average, 2007, for both cumulative and incremental scenarios.

Table 5-1: Predicted ground level mercury concentrations - five year average (µg/m³)

Location	Scenario: five year average				
	Cumulative	Vales Point	Eraring	Bayswater	Liddell
The Entrance	1.89E-06	5.57E-07	1.08E-06	2.01E-07	5.43E-08
Wyong	3.34E-06	1.01E-06	2.02E-06	2.50E-07	6.64E-08
Toukley	2.46E-06	8.09E-07	1.30E-06	2.76E-07	7.55E-08
Kanwal / Gorokan / Lake Haven	3.09E-06	1.17E-06	1.56E-06	2.87E-07	7.76E-08
Lake Munmorah	3.15E-06	1.33E-06	1.41E-06	3.29E-07	8.96E-08
Wyee	4.74E-06	1.54E-06	2.76E-06	3.43E-07	9.27E-08
Budgewoi	2.60E-06	9.10E-07	1.32E-06	2.94E-07	8.06E-08
Blue Haven	3.44E-06	1.52E-06	1.51E-06	3.18E-07	8.65E-08
Mannering Park	2.17E-06	5.98E-07	1.12E-06	3.56E-07	9.63E-08
Wyee Point	3.45E-06	1.16E-06	1.84E-06	3.64E-07	9.83E-08
Morisset	6.34E-06	1.67E-06	4.16E-06	4.01E-07	1.07E-07
Gwandalan	1.89E-06	3.49E-07	1.07E-06	3.71E-07	1.01E-07
Balmoral	3.86E-06	2.63E-07	3.04E-06	4.38E-07	1.20E-07
Swansea	1.90E-06	3.22E-07	1.07E-06	3.99E-07	1.11E-07
Newcastle (south)	2.46E-06	2.89E-07	1.53E-06	4.97E-07	1.36E-07
Newcastle (north)	2.25E-06	2.89E-07	1.28E-06	5.34E-07	1.53E-07
Toronto	3.83E-06	4.97E-07	2.74E-06	4.71E-07	1.31E-07
Woodrising	3.02E-06	3.43E-07	2.05E-06	4.93E-07	1.37E-07
Awaba	5.55E-06	7.04E-07	4.24E-06	4.80E-07	1.31E-07
West Wallsend	2.93E-06	4.13E-07	1.77E-06	5.89E-07	1.64E-07
Cessnock	3.47E-06	4.43E-07	2.14E-06	6.98E-07	1.87E-07
Kurri Kurri	3.00E-06	3.59E-07	1.71E-06	7.26E-07	2.08E-07
Maitland	2.31E-06	2.60E-07	1.11E-06	7.13E-07	2.22E-07
Greta	2.74E-06	2.70E-07	1.16E-06	9.99E-07	3.07E-07
Branxton	2.81E-06	2.69E-07	1.13E-06	1.08E-06	3.28E-07
Singleton (south)	3.30E-06	2.37E-07	9.72E-07	1.62E-06	4.76E-07
Singleton (north)	3.40E-06	2.29E-07	9.36E-07	1.71E-06	5.17E-07
Muswellbrook	2.69E-06	1.45E-07	5.57E-07	1.34E-06	6.53E-07
Aberdeen	1.64E-06	1.17E-07	4.51E-07	7.88E-07	2.81E-07
Denman	2.58E-06	1.59E-07	6.21E-07	1.50E-06	3.03E-07
Camberwell	4.31E-06	2.03E-07	8.17E-07	2.45E-06	8.43E-07
Max level in domain	**6.02E-06**	**1.71E-07**	**6.61E-07**	**2.39E-06**	**2.80E-06**

Table 5-2: Predicted ground level mercury concentrations - maximum one year average, 2007 (µg/m³)

Location	Scenario: maximum one- year average				
	Cumulative	Vales Point	Eraring	Bayswater	Liddell
The Entrance	2.66E-06	9.16E-07	1.10E-06	3.04E-07	3.38E-07
Wyong	4.65E-06	1.69E-06	2.18E-06	3.74E-07	4.02E-07
Toukley	3.51E-06	1.32E-06	1.29E-06	4.17E-07	4.78E-07
Kanwal / Gorokan / Lake Haven	4.67E-06	2.01E-06	1.75E-06	4.28E-07	4.81E-07
Lake Munmorah	4.85E-06	2.32E-06	1.50E-06	4.78E-07	5.55E-07
Wyee	6.77E-06	2.51E-06	3.19E-06	5.04E-07	5.72E-07
Budgewoi	3.88E-06	1.55E-06	1.37E-06	4.41E-07	5.12E-07
Blue Haven	5.44E-06	2.68E-06	1.75E-06	4.75E-07	5.43E-07
Mannering Park	3.25E-06	9.16E-07	1.22E-06	5.12E-07	5.95E-07
Wyee Point	4.93E-06	1.85E-06	1.96E-06	5.23E-07	6.08E-07
Morisset	7.04E-06	1.47E-06	4.37E-06	5.57E-07	6.47E-07
Gwandalan	2.55E-06	5.16E-07	8.97E-07	5.29E-07	6.04E-07
Balmoral	4.27E-06	2.92E-07	2.63E-06	6.43E-07	7.09E-07
Swansea	2.90E-06	4.95E-07	1.11E-06	6.11E-07	6.80E-07
Newcastle (south)	3.92E-06	4.94E-07	1.69E-06	8.34E-07	8.94E-07
Newcastle (north)	3.79E-06	4.68E-07	1.35E-06	9.27E-07	1.05E-06
Toronto	5.23E-06	6.12E-07	3.12E-06	7.15E-07	7.85E-07
Woodrising	4.38E-06	3.98E-07	2.34E-06	7.86E-07	8.59E-07
Awaba	6.22E-06	1.02E-06	3.76E-06	6.89E-07	7.57E-07
West Wallsend	4.14E-06	6.78E-07	1.46E-06	9.56E-07	1.04E-06
Cessnock	4.55E-06	6.23E-07	1.99E-06	9.19E-07	1.02E-06
Kurri Kurri	4.36E-06	5.08E-07	1.49E-06	1.11E-06	1.25E-06
Maitland	4.31E-06	4.28E-07	1.13E-06	1.28E-06	1.48E-06
Greta	4.93E-06	3.98E-07	1.07E-06	1.62E-06	1.84E-06
Branxton	5.07E-06	4.10E-07	1.02E-06	1.70E-06	1.94E-06
Singleton (south)	6.16E-06	3.41E-07	8.42E-07	2.32E-06	2.65E-06
Singleton (north)	6.60E-06	3.29E-07	8.08E-07	2.53E-06	2.93E-06
Muswellbrook	6.43E-06	1.91E-07	4.59E-07	1.95E-06	3.83E-06
Aberdeen	3.29E-06	1.60E-07	3.72E-07	1.10E-06	1.66E-06
Denman	5.55E-06	2.18E-07	5.05E-07	2.75E-06	2.08E-06
Camberwell	1.00E-05	2.82E-07	6.86E-07	4.12E-06	4.92E-06
Max level in domain	**1.184E-05**	**2.03E-06**	**1.03E-05**	**1.01E-05**	**3.26E-06**

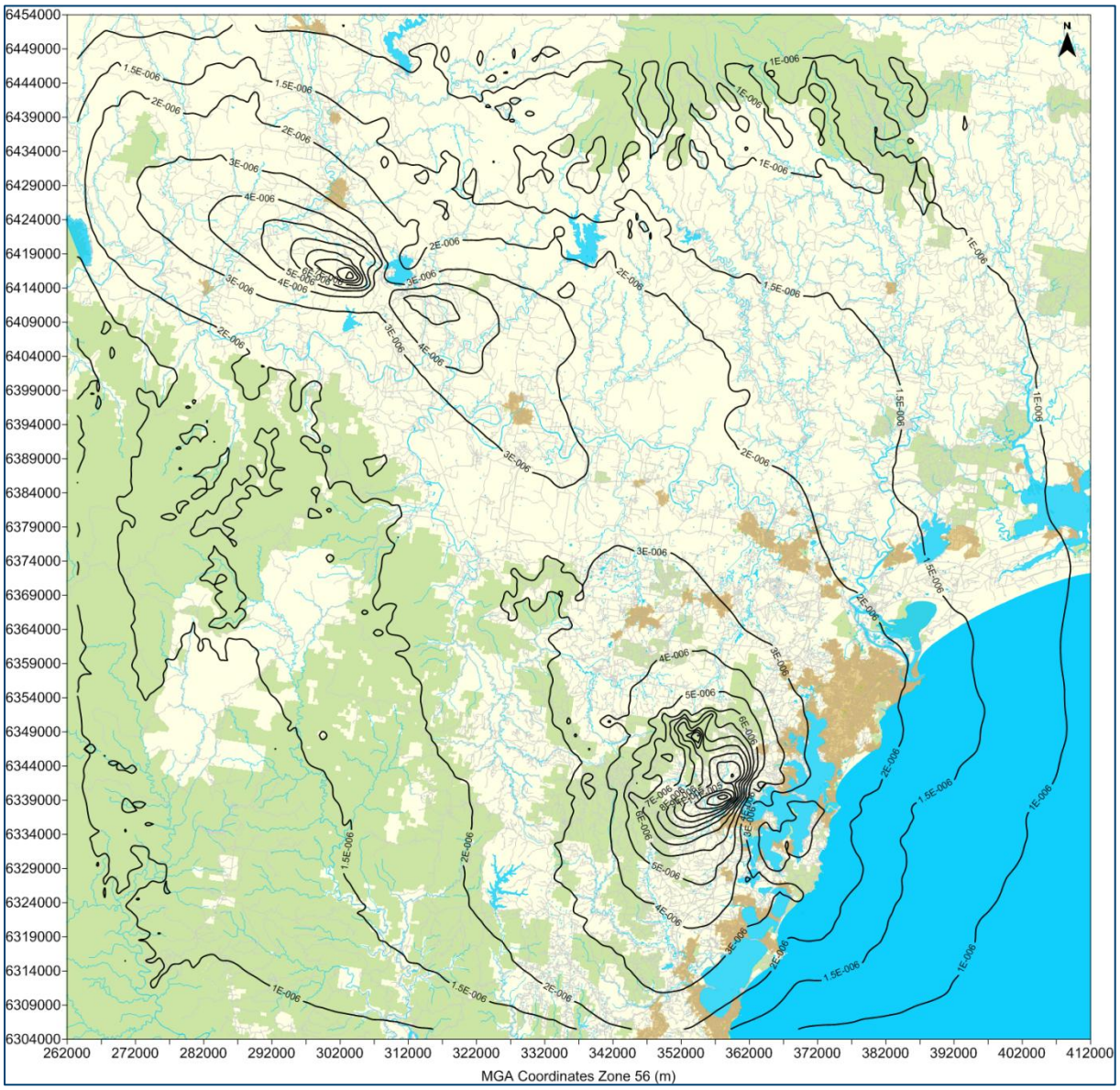

Figure 5-2: Cumulative five year average (2007-2011) (µg/m³)

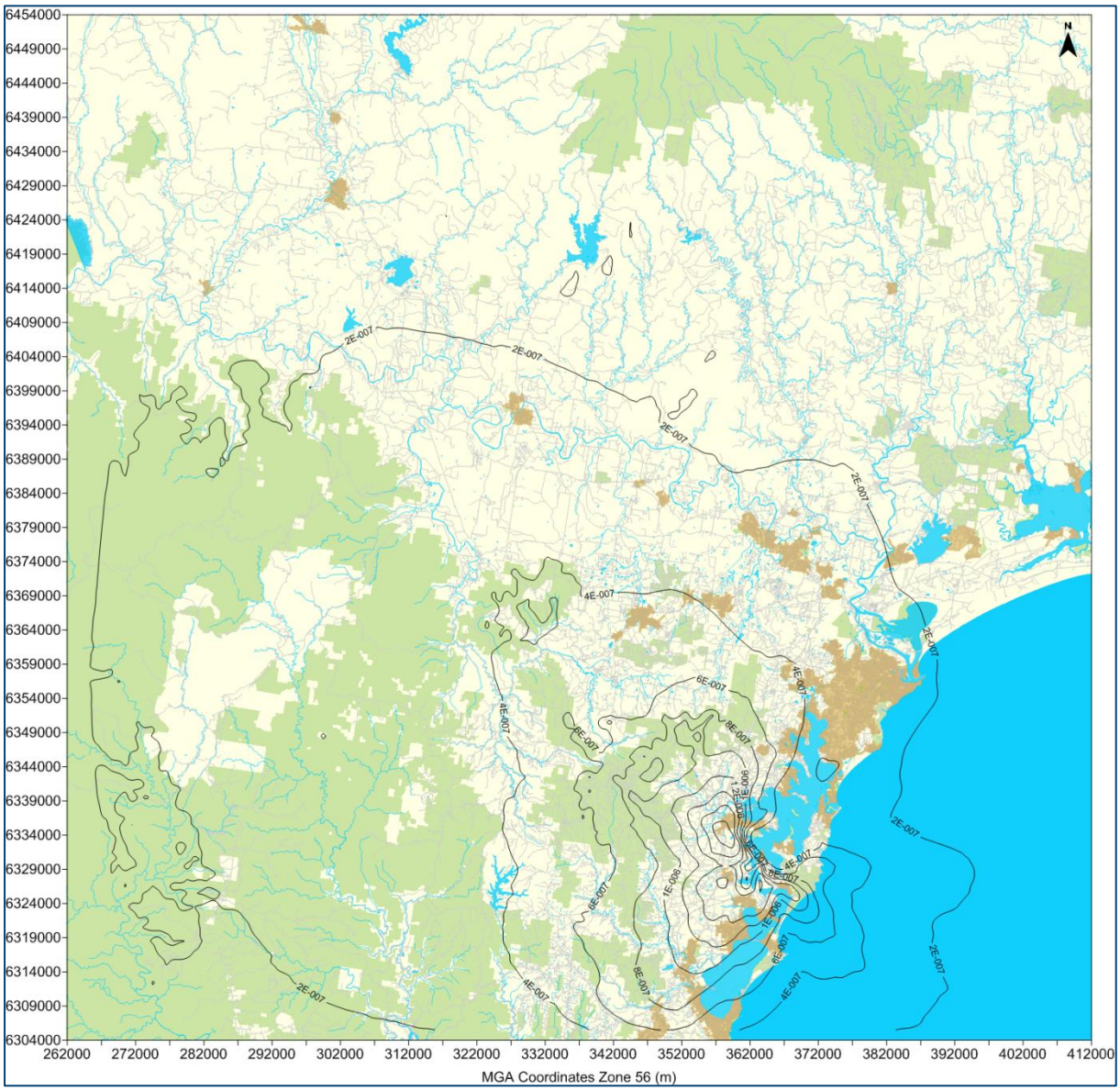

Figure 5-3: Vales Point Power Station - five year average (2007-2011) (µg/m³)

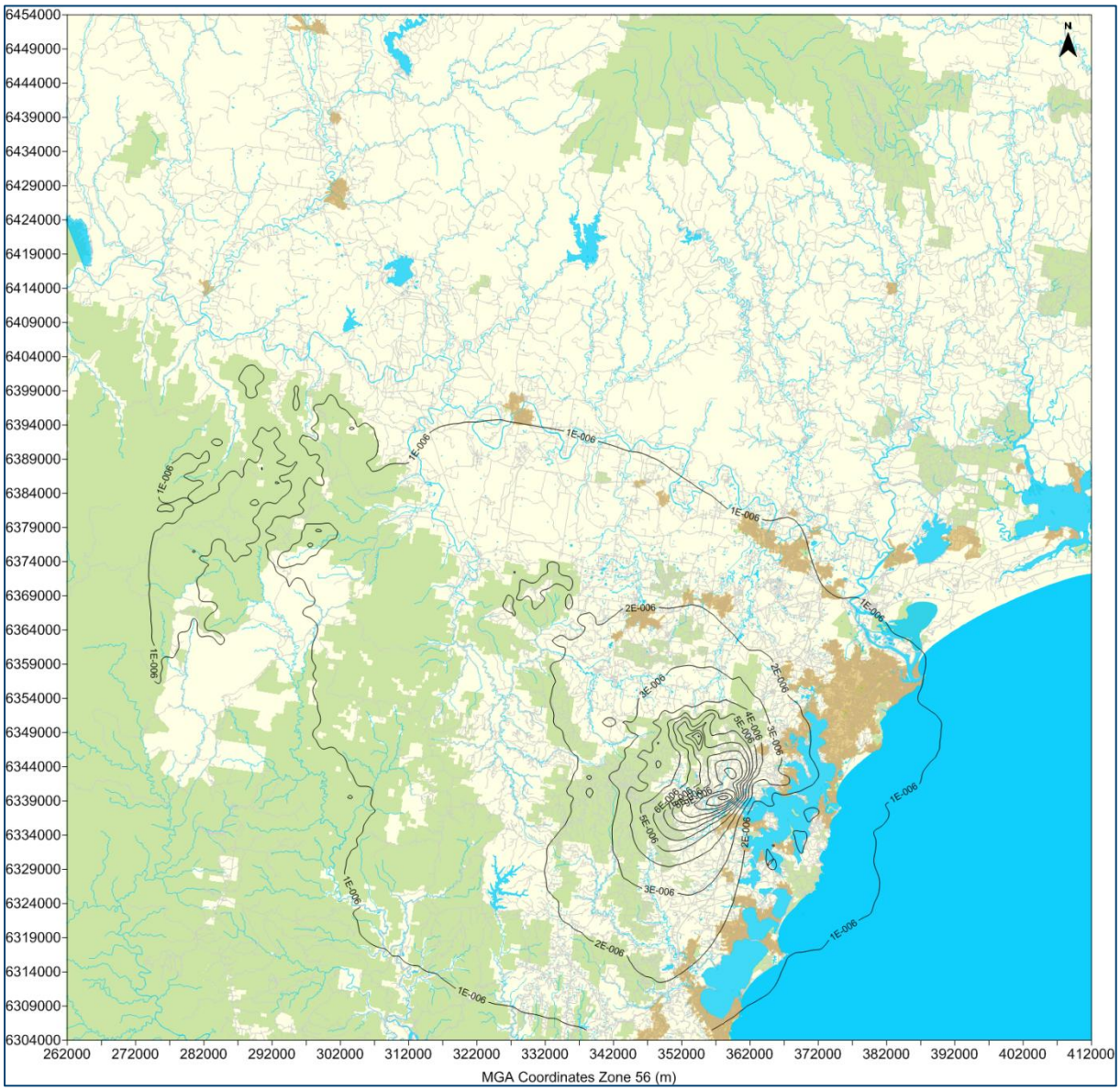

Figure 5-4: Eraring Power Station - five year average (2007-2011) (µg/m³)

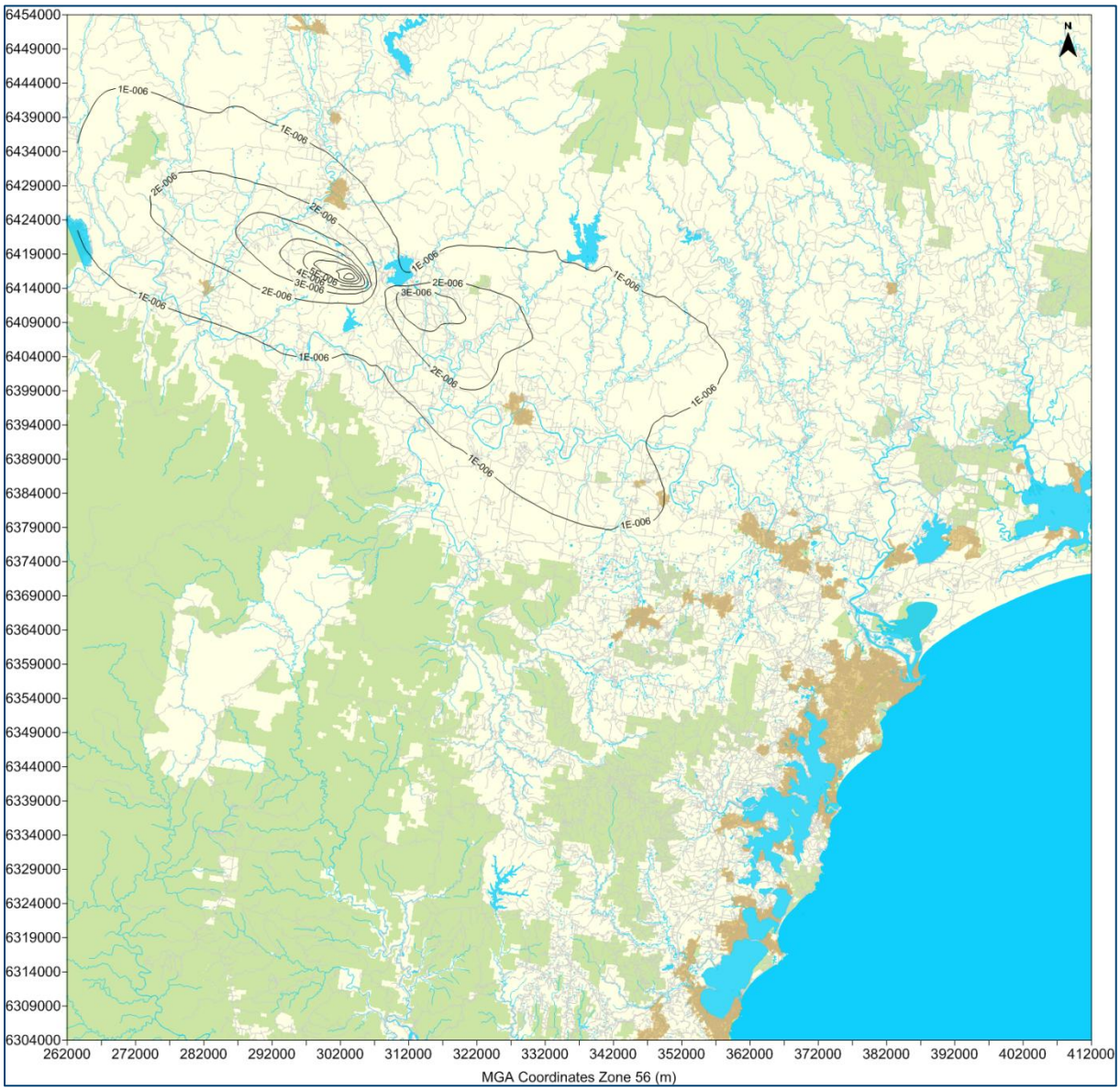

Figure 5-5: Bayswater Power Station - five year average (2007-2011) (µg/m³)

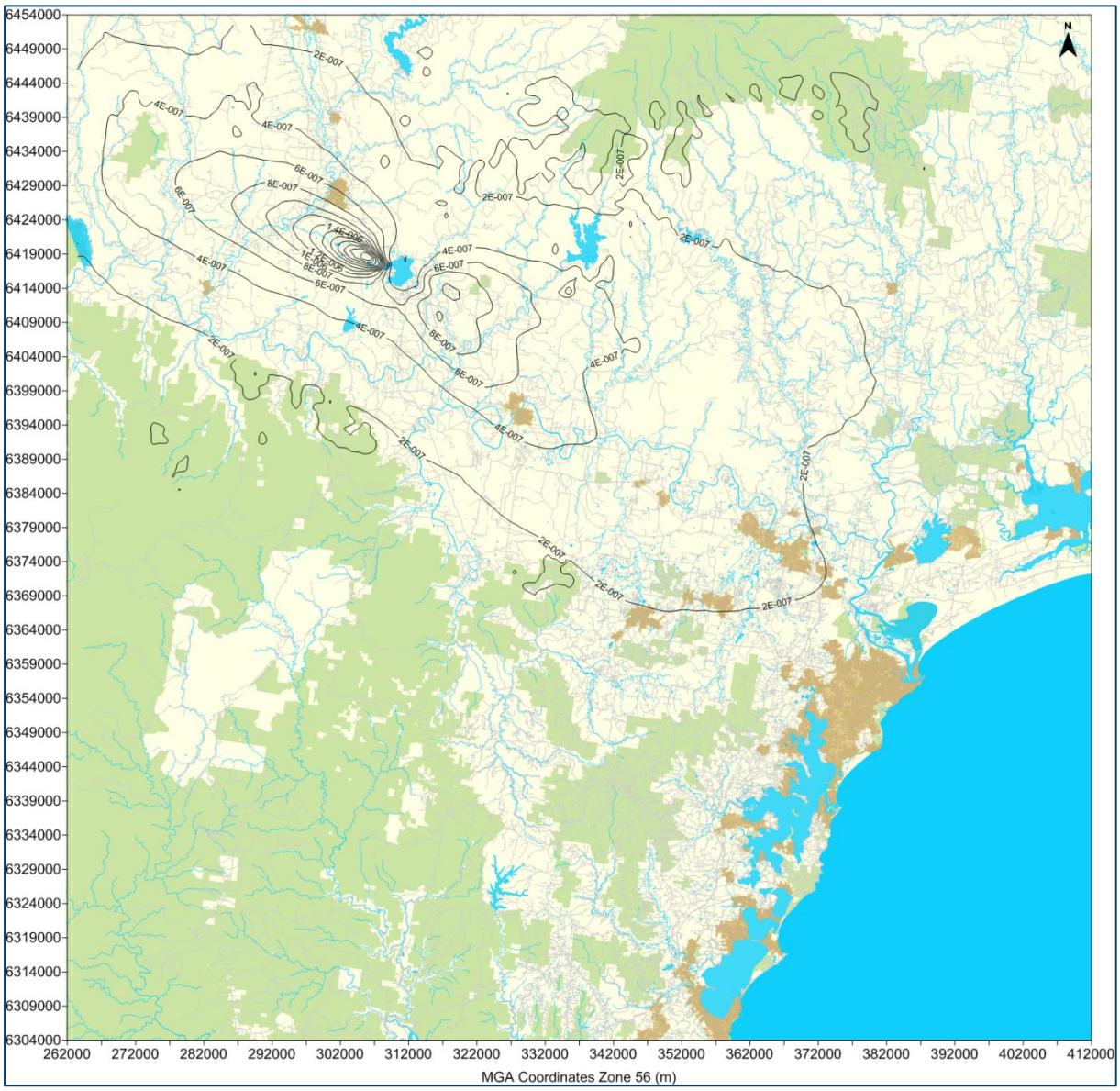

Figure 5-6: Liddell Power Station - five year average (2007-2011) (µg/m³)

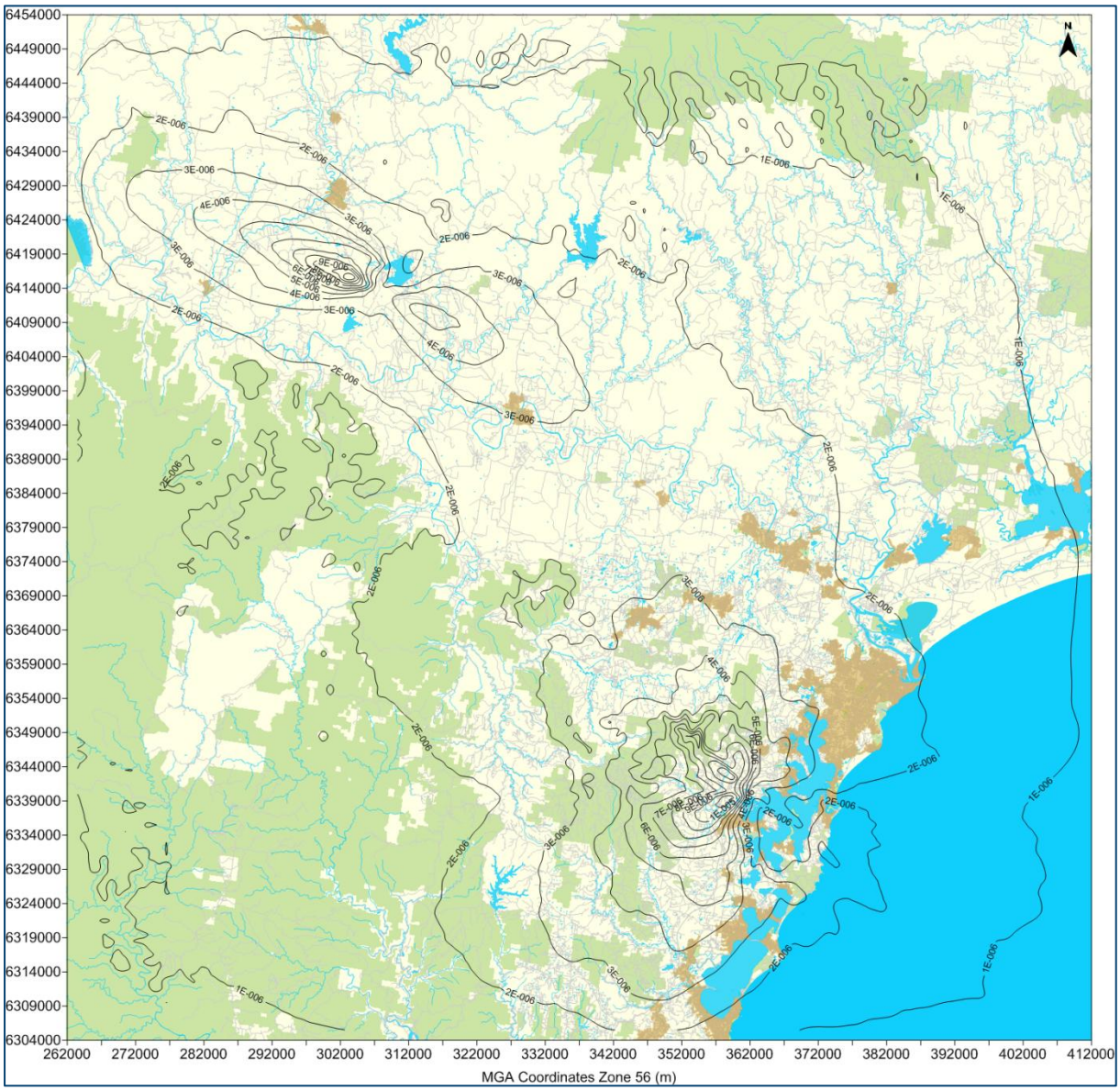

Figure 5-7: Cumulative maximum impact annual average (2007) (µg/m³)

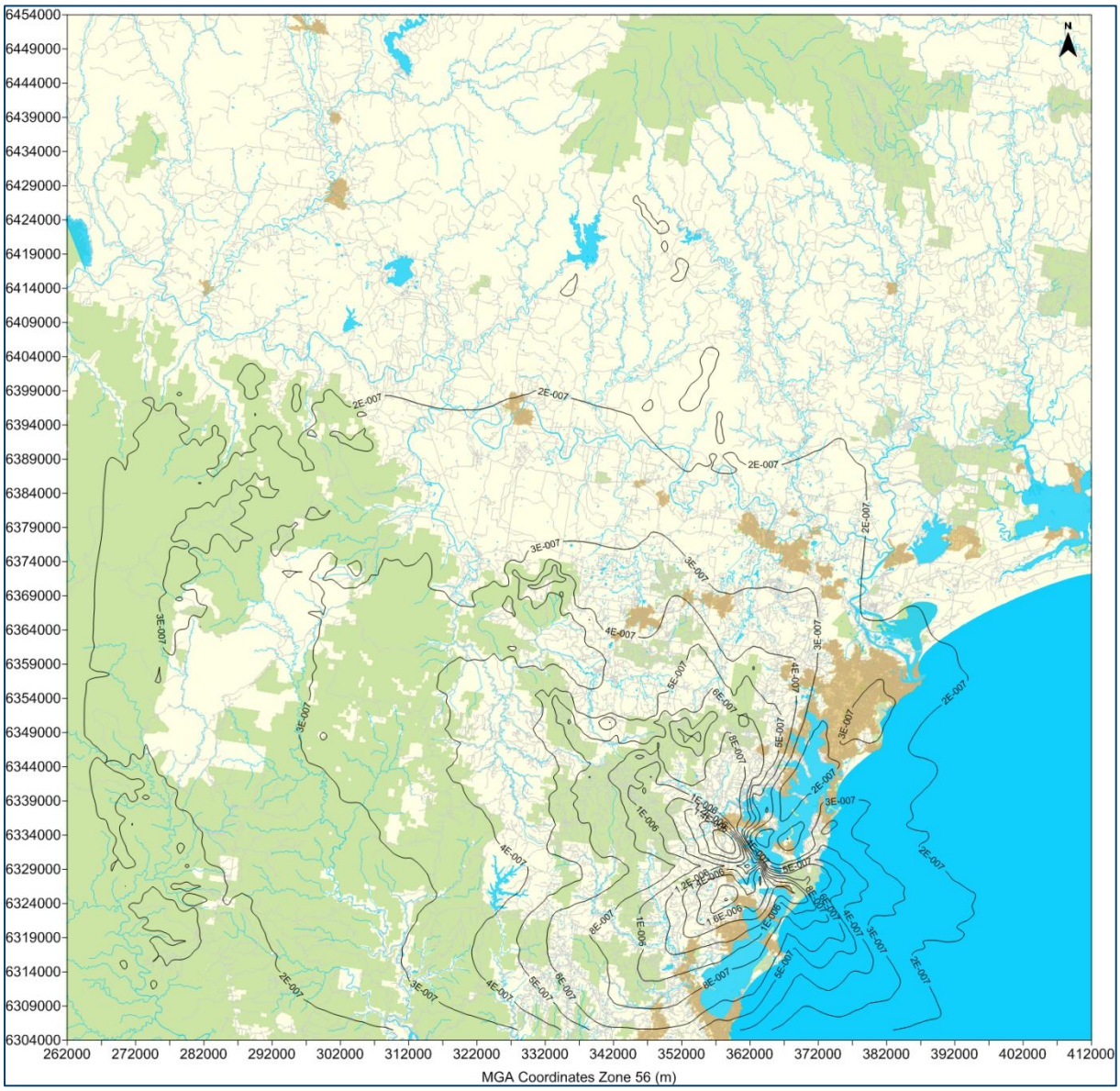

Figure 5-8: Vales Point Power Station - maximum impact annual average (2007) (µg/m³)

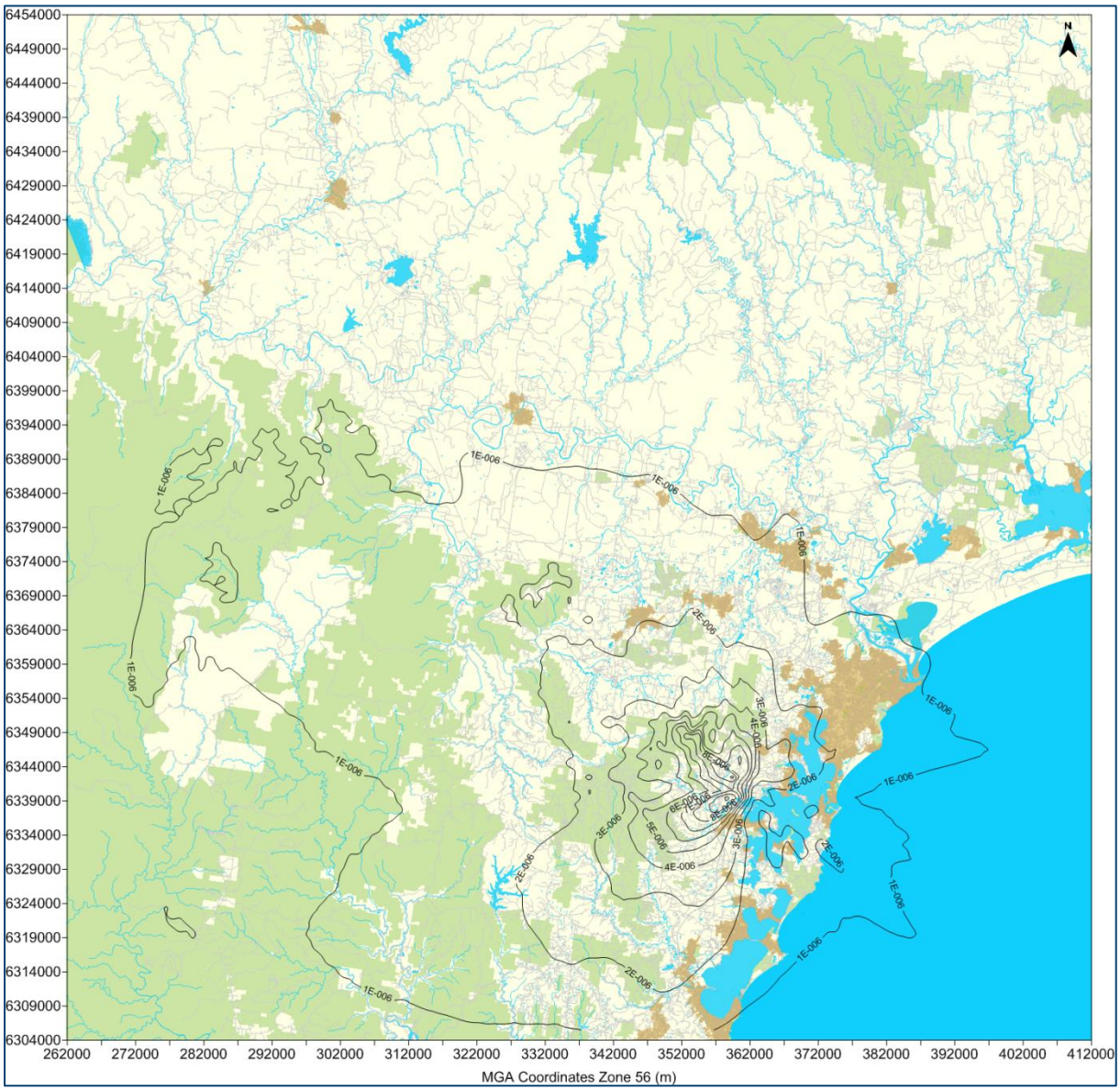

Figure 5-9: Eraring Power Station - maximum impact annual average (2007) (µg/m³)

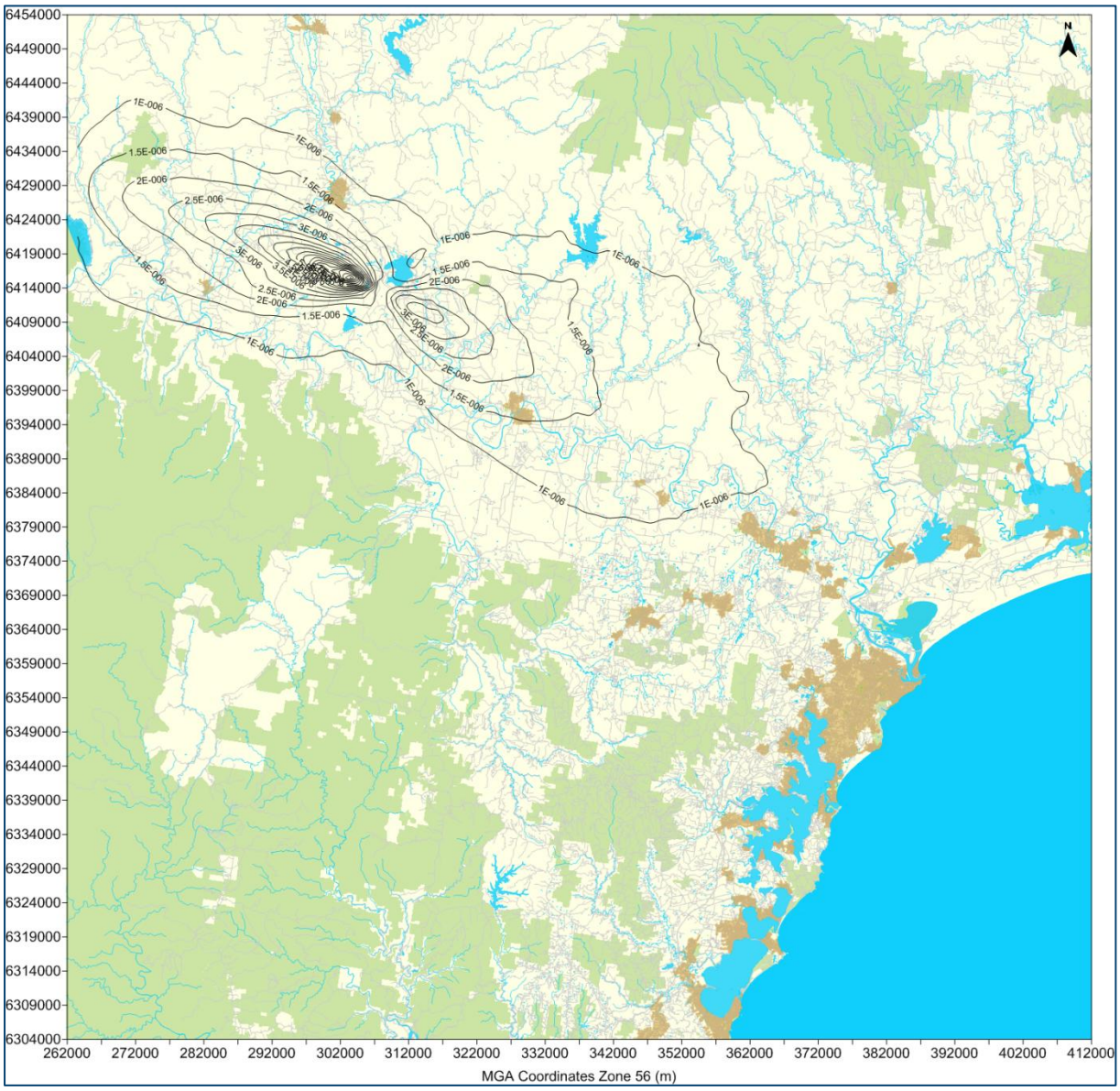

Figure 5-10: Bayswater Power Station - maximum impact annual average (2007) (µg/m³)

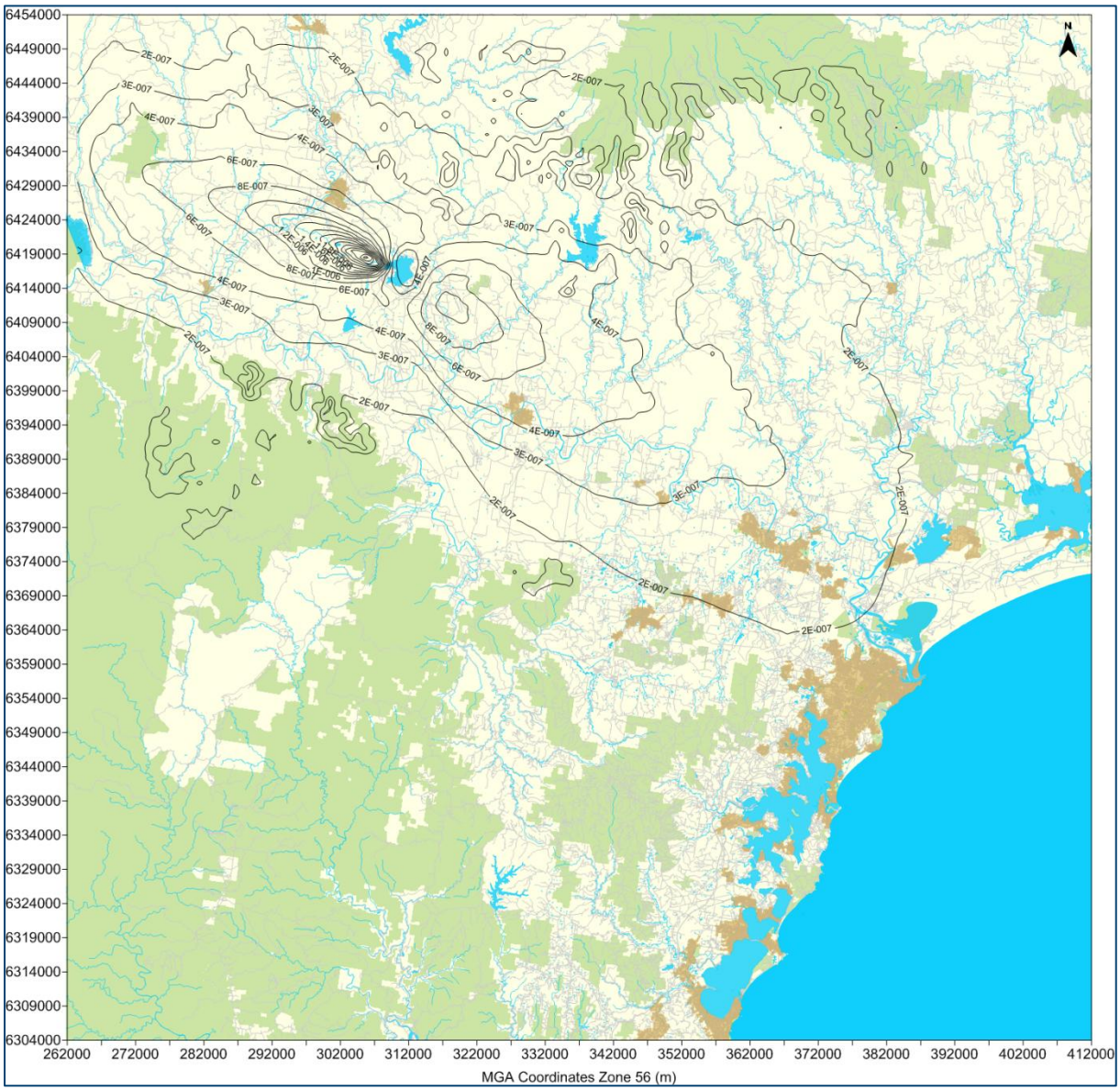

Figure 5-11: Liddell Power Station - maximum impact annual average (2007) (µg/m³)

6 CONCLUSIONS

This study has used advanced air dispersion modelling techniques to predict potential ground level concentrations of mercury that may result from emissions generated from the coal fired power generators in the Hunter Valley region. The modelling was conducted for a five year period. Five year average values and the highest of the five annual average values are presented at various receptor locations in tables and graphically as isopleths diagrams.

The results indicate that for the coal fired power generators located on the shores of Lake Macquarie (i.e. Vales Point and Eraring), the highest mercury concentrations occur to the west. The highest localised levels occur in receptor areas with elevated terrain.

The upper Hunter Valley power stations (i.e. Bayswater and Liddell) show the highest levels along a northwest and southeast axis, with the higher levels to the northwest. The highest localised levels occur in receptor areas with elevated terrain.

In all cases the highest results appear to be low relative to NSW EPA impact assessment criteria.

The potential health impacts of mercury are generally due to chronic, and not acute exposure, however the NSW impact assessment criteria for mercury are set at an hourly average level. The results of this study should therefore be used in a human health risk assessment, which can then be relied on to determine any potential effects on human health from the power station mercury emissions.

7 REFERENCES

TRC (2011)

"Generic Guidance and Optimum Model Settings for the CALPUFF Modeling System for Inclusion into the Approved Methods for the Modeling and Assessments of Air Pollutants in NSW, Australia'". Prepared for the NSW Office of Environment and Heritage by TRC Environmental Corporation.