Department of
Environment and Conservation

Ambient Monitoring of Sulfur Dioxide in Kalgoorlie, 1999 - 2008

Technical Report





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Prepared by
Department of Environment and Conservation
Air Quality Management Branch

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Definitions and abbreviations

AIR	Kalgoorlie Airport monitoring station
Air NEPM	Ambient Air Quality National Environmental Protection Measure
Ambient air	The layer of air, five metres thick immediately above and immediately surrounding, the external surfaces of any residential premises situated in a protected area and immediately above the surface of the remainder of a protected area
BoM	Bureau of Meteorology
BSY	Boulder Shire Yard monitoring station
Clock hour average	Clock hour averages are calculated by averaging data that finishes only at the end of each hour. Clock hour averages are constrained to finish only on the hour (see Appendix 2).
CPS	Coolgardie Primary School monitoring station
DEC	Department of Environment and Conservation
EPHC	Environment Protection Heritage Council (incorporates the NEPC)
EPP	Environmental Protection Policy
HGC	Hannans Golf Course monitoring station
KAM	Kambalda monitoring station
KCGM	Kalgoorlie Consolidated Gold Mines Pty Ltd
KCY	Kalgoorlie Council Yard monitoring station
KRH	Kalgoorlie Regional Hospital monitoring station
KUR	Kurrawang Aboriginal Reserve monitoring station
MEX	Metals Explorations monitoring station
Moving average	Moving averages are calculated by running an appropriately sized window across the data in small increments (down to the maximum time resolution of the data base) and for each point, calculating the required average from the relevant number of data points up to that period. Moving averages are not constrained to finish on the hour. (see Appendix 2)
NEPC	National Environment Protection Council
NEPM	National Environment Protection Measure
NPI	National Pollutant Inventory
Percentile	Value of a variable below which a certain percent of observations fall
ppm	parts per million by volume (one ppm is equivalent to 1000 ppb)
ppb	parts per billion by volume (one ppb is equivalent to 0.001 ppm)
SAT	Satellite monitoring station
SO_2	sulfur dioxide
ug/m^3	micrograms per cubic metre at 0 ^oC and 101325 Pa.
WFY	Westrail Freight Yard monitoring station

SUMMARY

The city of Kalgoorlie is located in the Western Australian goldfields, 595 km east of Perth. The major industries in the region are nickel and gold mining and ore processing activities. These activities are known to increase air emissions particularly sulfur dioxide (SO_2) in the local airshed. This report provides a detailed assessment of ambient SO_2 data collected for the Kalgoorlie region for 1999 to 2008, and examines the future monitoring requirements for the Kalgoorlie region.

Since the 1980s, industrial processes in the Goldfields area have contributed to high levels of SO_2 in the air. An Environmental Protection Policy (EPP) designed to control the concentrations of SO_2 in the air over residential areas was gazetted in 1988. This EPP was modified in 1992 to incorporate the residential areas of Coolgardie, Kambalda and Kurrawang Aboriginal Reserve. The EPP was reviewed and further revised in 2003. Apart from the addition of residential areas, the main change to the EPP across these three stages was the progressive tightening of the ambient SO_2 concentration objectives. These objectives (variously named) have included a not-to-be-exceeded limit concentration plus one or more 'standards' for assessing acceptability. At the time of writing, the not-to-be-exceeded one-hour limit concentration is 0.25 ppm and the one-hour "standard" (although no longer called this) is 0.2 ppm with an exceedence allowance of one day per year. This EPP "standard" is, by design", equivalent to the one-hour goal for SO_2 set by the National Environment Protection Council (Ambient Air Quality) Measure (NEPM).

Industries that emit SO_2 are required to comply with the EPP limit concentration under a condition of licence. SO_2 has been monitored in the EPP area since the 1980s by these industries and by the predecessor of DEC in early years.

Ambient air monitoring is conducted at seven monitoring stations distributed in the city of Kalgoorlie-Boulder and one each in Coolgardie, Kambalda and Kurrawang.

Data collected for the Goldfields EPP areas between 1999 and 2008 has been compared to the standards and limits laid out in the 1992 and 2003 Environmental Protection (Goldfields Residential Areas) (Sulfur Dioxide) Policy standards (EPP 1992 and EPP 2003).

An overview of findings is provided below.

- The Environment Protection Policy (EPP) one-hour SO_2 concentration standard was exceeded 21 times during the 10 year period 1999 to 2008 (once in 1999, 11 times in 2000, 4 times in 2001, twice in 2005, twice in 2006 and once in 2007). However, considering the allowable exceedences of the standard specified in the EPP for each year, the only year in which the number of exceedences was greater than that allowed was 2000;

- In the period 1999 to 2008 the EPP limit for SO_2 was exceeded at one site, in 2005; and

- Monitoring data collected during the period 1999 to 2008 has shown an overall decrease in SO_2 concentration at all stations.

The effectiveness of the 1992 and 2003 EPPs in reducing SO2 concentrations towards meeting the NEPM goals is assessed in this report. In summary:

- The NEPM goal for the one-hour standard was met at the majority of sites within the defined EPP areas during the period 1999 to 2008. In 2000, both the AIR and KCY sites did not meet the NEPM goal;

- The NEPM goal for both the 1-day and 1 year standard for SO_2 were met at all sites within the Kalgoorlie EPP areas during the period 1999 to 2008.

During the period from 22 December 2008 to 16 March 2009, SO_2 was measured using passive samplers at 6 locations. Four locations were outside the defined EPP areas while two were within the city of Kalgoorlie. These sites were chosen to establish the SO_2 exposure to the general population living and/or transiting through areas outside the defined EPP areas, where a number of air quality related complaints were received in recent years. The maximum weekly SO_2 concentration using these passive samplers during this period was 0.087 ppm recorded at the Goldfields Highway site which is located outside the defined EPP areas.

While SO_2 concentrations in the Kalgoorlie EPP defined areas has few exceedences of the EPP or NEPM standards, the continuous monitoring at the Satellite monitoring station near the Gidji Roaster and the limited Radiello sampling indicates that SO_2 concentrations outside the EPP areas near major sulphur dioxide emission sources are much higher.

1.0 INTRODUCTION

Sulfur dioxide (SO_2) is a colourless, water-soluble, non-combustible gas with a sharp, irritating odour. This gas and its reaction products (sulfuric acid and sulfate particles) are removed from the atmosphere by wet (i.e. rain) and dry deposition (i.e. by direct uptake of sulphur at soil, plant and water surfaces).

Anthropogenic activities which are sources of SO_2 are power generation from the combustion of coal, oil or gas containing significant amounts of sulfur, the roasting or smelting of mineral ores containing sulfur, oil refining, and industrial plants which burn large quantities of fuels with a significant sulfur content, and in urban areas, motor vehicles.

Australian towns and cities generally have low levels of SO_2 in the ambient air when compared to other countries around the world (DEC 2004) but some sites such as Port Pirie and Mt Isa do experience periods of high SO_2 concentrations.

The highest SO_2 concentrations are generally located around oil refineries, chemical manufacturing industries, mineral ore processing plants and power stations. There have been a number of comprehensive studies (e.g. Ayers et al., 1979; 1981; 1982, Bigg et al., 1978 a; 1978 b) of SO_2 in and around Mt Isa. These include oxidation rates of SO_2 to sulphate aerosol in the plume emitted from the smelter, SO_2 concentrations, the dry deposition velocity and flux to the surface and penetration into homes.

Natural sources producing SO_2 include volcanic and geothermal activity. As well, bacterial and algal processes can produce organic sulfur compounds which are readily converted to SO_2. Natural sources typically contribute less than one per cent of total ambient SO_2 in urban areas.

This report provides an assessment of data from January 1999 to December 2008 for ambient SO_2 concentration in the Kalgoorlie area. This analysis has been undertaken in response to an increase in complaints relating to air quality in the Kalgoorlie/Goldfields area and is not to be taken as a review of the Goldfields EPP. The objectives of the study are to:

- Compare SO_2 concentrations in the Goldfields EPP area with the relevant 1992 and 2003 EPP standards and limits;
- Examine day-night and seasonal variation in SO_2 concentrations;
- Determine if and when periods of high concentrations occur; and
- Assess SO_2 concentrations outside the Goldfields EPP region

During the period 22 December 2008 to 16 March 2009 SO_2 concentrations were measured with Radiello passive samplers at an additional 6 sites both within and outside the defined Goldfields EPP areas. These sites were chosen to establish SO_2 exposure of both general and transient populations within and outside the defined Goldfields EPP areas where a number of complaints have been received regarding SO_2 or odorous plumes.

The study is a component of a systematic review of the current air quality in the Kalgoorlie area which will support the development of an air quality management strategy for Kalgoorlie. The overall aim is to provide government and industry a basis for decision making on key issues such as land use planning and infrastructure development. This will provide for the ongoing maintenance of acceptable air quality in the area while accommodating for the impact of future development.

The study area includes Kalgoorlie, which is located in the Western Australian goldfields, 595km east of Perth with a population of approximately 30,000, Coolgardie which is approximately 32km west of Kalgoorlie and has a population of 4,000, Kambalda which is 50 km south of Kalgoorlie with a population of approximately 2,700 (ABS 2008) and Kurrawang which is 12km west of Kalgoorlie and has a population of approximately 100 people (ABS 2008). Nickel and gold mining and processing are the major regional industries.

1.1 Sources of sulfur dioxide in Kalgoorlie

Kalgoorlie is a mining town, and the dominant sources of SO_2 are from gold and nickel ore processing, roasting and smelting.

A large proportion of metallic minerals in the Kalgoorlie region are compounded with sulfide minerals. During processing the metallic ore is separated and concentrated by flotation, then roasted in a sulfide oxidisation process that releases sulfur dioxide gas. The concentrate is then subjected to a metallurgical process for leaching gold from ore by converting the gold to water soluble ions to extract the gold (Mine Engineer 2009).

The National Pollutant Inventory (NPI) has identified basic non-ferrous metal manufacturing (i.e., roasting and smelting operations) as the greatest contributor of SO_2 emissions to the Kalgoorlie air shed for the 2007/8 financial year (Figure 1). Basic non-ferrous metal manufacturing produced approximately 210,000 tonnes of SO_2 emissions for the 2007/8 financial year. Metal ore mining was the second largest emitter, releasing approximately 21,000 tonnes annually. Other sources were motor vehicles (64 tonnes) and Rail (7.7 tonnes) with the remainder comprising less than 0.02 per cent of the total.

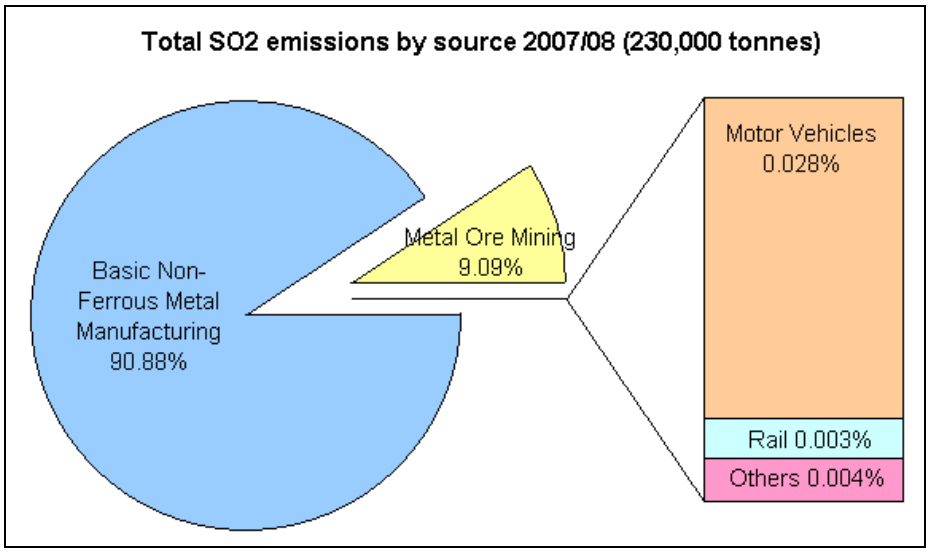


Figure 1 2005/6 Kalgoorlie SO_2 emissions by source category (NPI 2008)

The NPI has identified the following major point sources of SO_2 emissions to the Kalgoorlie air shed:

- **Gidji roaster**
  This facility is owned by Kalgoorlie Consolidated Gold Mining (KCGM) is a gold roasting and extraction facility commissioned in the early 90s. It is located approximately 12km north of northern border of the Kalgoorlie EPP area.

  The roaster undertakes the process of oxidising refractory sulfide concentrate sourced from the Fimiston Mill and is the greatest SO_2 emitter in WA with 190,000 tonnes released during 2000/1 to 180,000 tonnes in 2005/6 (NPI 2008). On average, between July 2000 and June 2006, 175,000 tonnes per year of SO_2 was emitted from the roaster.

  The current operational licence for the Gidji Roaster is prescribed within two categories:

  (i) metal smelting or refining and

  (ii) processing or beneficiation of metallic ore

  KCGM in conjunction with BHP Billiton Nickel West and Kanowna Belle Gold Mines is required to monitor SO_2 emissions at the following 10 monitoring stations, as shown in Figure 2:

- Boulder Shire Yard (BSY)
- Hannans Golf Course (HGC)
- Kalgoorlie Airport (AIR)
- Kalgoorlie Council Yard (KCY)
- Kalgoorlie Regional Hospital (KRH)
- Metals Exploration (MEX)
- Westrail Freight Yard (WFY)
- Kurrawang Aboriginal Reserve (KUR)
- Kambalda town site (KAM) and
- Coolgardie Primary School (CPS)

The locations of monitoring stations and Environmental Protection Policy areas are identified in Figure 2. For additional monitoring station descriptions please refer to section 3.0 on sampling location and monitoring method.

- **Kalgoorlie nickel smelter**

This facility is located 8 km south of Kalgoorlie and has been operational since 1973. The smelter is owned and operated by BHP Billiton Nickel West. The smelter uses a flash smelting method, whereby dry sulphide nickel concentrate is fed into the furnace and oxidised, resulting in SO_2 being produced and emitted.

The emissions from the flash furnace are treated and passed through a sulphuric acid plant (installed in 1996) which removes the majority of the SO_2 from the gas stream prior to discharge. The nickel matt from the flash furnace is then sent to converters where residual sulfur and other impurities are driven off. The converters are the main source of SO_2 from this facility with emissions from the acid plant and to a lesser degree from fuel combustion (WMC 2008) contributing to the overall site emissions.

The Kalgoorlie Nickel Smelter is prescribed within four NPI categories,

(i) chemical manufacturing
(ii) metal smelting or refining
(iii) electric power generation
(iv) fuel burning.

As a condition of the licence, stack emission monitoring must also be conducted in conjunction with ambient sulfur dioxide monitoring.

BHP Billiton are required to monitor SO_2 emissions at the same 10 monitoring stations as required by KCGM. These stations are KRH, HGC, KCY, AIR, MEX, BSY, WFY, KAM, COO, KUR (Figure 2).

- **Kanowna Belle gold roaster**

This facility is located 16km north-east of Kalgoorlie and has been in operation since 1994. It is owned by Barrick Ltd. The process used is similar to the KCGM Roaster. SO_2 emissions for the 2005 calendar year were reported to be 24,000 tonnes.

The Kanowna Belle Gold Roaster is prescribed within three NPI categories,

(i) Processing/Beneficiation of metallic ore
(ii) mine dewatering and
(iii) sewage facility.

Barrick Ltd is required to monitor SO_2 emissions at the same 10 monitoring stations as KCGM and BHP Billiton for the Kalgoorlie nickel smelter and Gidji roaster operations.

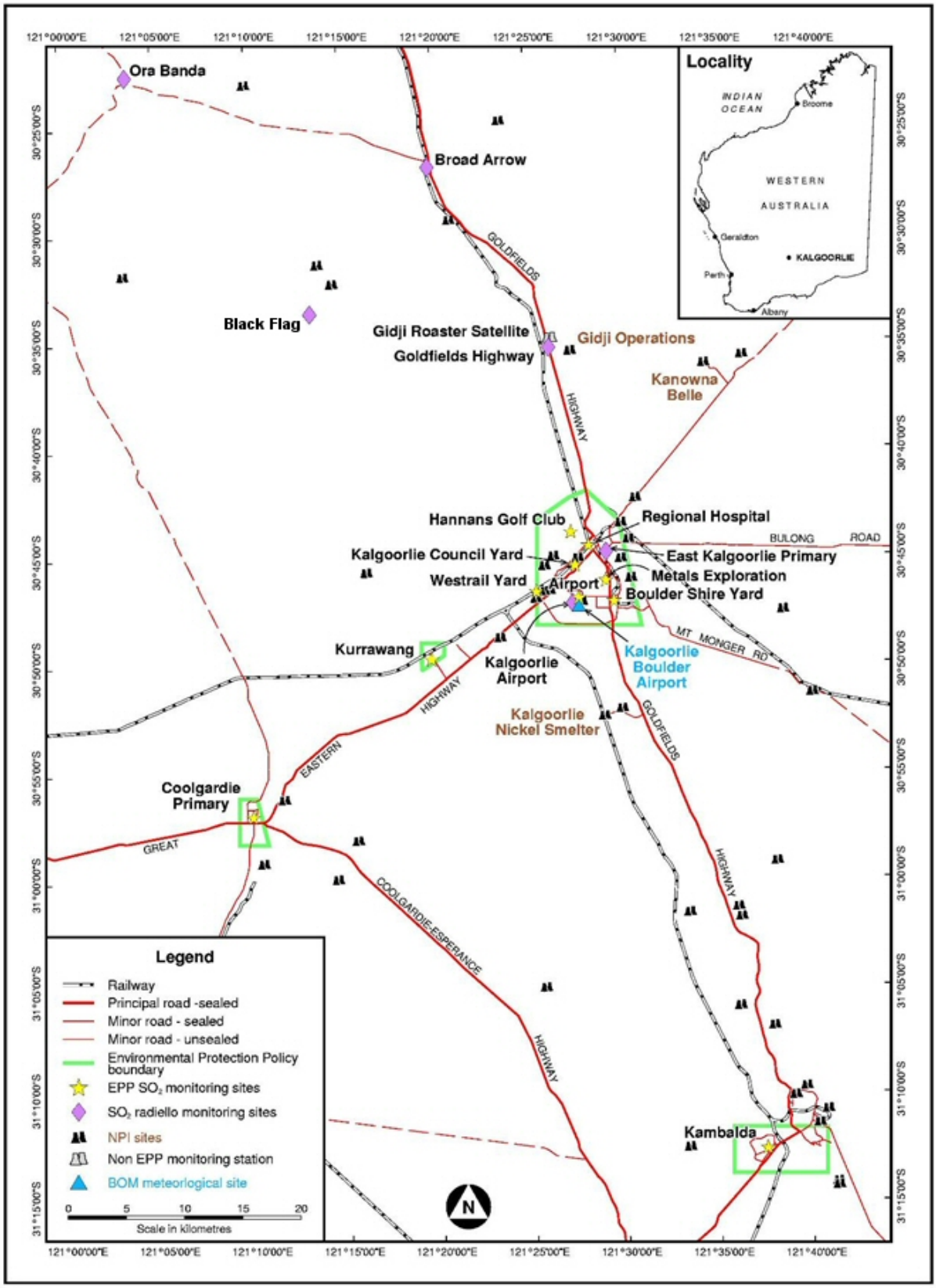


Figure 2 Location of the SO_2 monitoring stations and the major SO_2 sources in the Goldfields region of Western Australia

1.2 Health and ecosystem impact of sulfur dioxide

Sulfur dioxide can undergo chemical reactions in the atmosphere to produce sulphuric acid. The process takes up to a week to complete and takes place via the following steps:

- SO_2 reacts with hydroxyl radicals in the presence of nitrogen (N_2) and oxygen (O_2) in the atmosphere to produce the radical $HOSO_2$• via the following reaction.
- $SO_2 + OH• \rightarrow HOSO_2•$
- $HOSO_2$• then reacts rapidly to form $HO_2• + SO_3$
- In the presence of water, sulfur trioxide (SO_3) reacts to form sulfuric acid (H_2SO_4)
- $SO_3 + H_2O \rightarrow H_2SO_4$

Sulfur dioxide can also interact with other gases and particles in the air to form sulphates. Due to the way SO_2 reacts with other substances in the air, it can be associated with a wide variety of health and environmental impacts. These impacts are outlined below.

Within an atmospheric boundary layer depth of 1000 metres and a deposition velocity of 1 cm sec^{-1}, SO_2 has a physical lifetime of about 3 – 5 days.

1.2.1 Health effects

Sulfur dioxide is highly soluble and readily absorbed in the upper respiratory tract. The response to sulfur dioxide is rapid, occurring within the first few minutes of exposure. The acute effects of sulfur dioxide exposure include reductions in lung function (e.g. FEV1), increases in airway resistance and symptoms such as wheezing and shortness of breath. These effects are enhanced when breathing is through the mouth as commonly occurs during exercise or heavy exertion. Information on the acute effects of sulfur dioxide has come primarily from controlled exposure studies using volunteers. One of the general findings from these studies is that there is a continuous spectrum of sensitivity to sulfur dioxide, with some people being completely unaffected by concentrations that lead to severe bronchoconstriction in others (WHO, 2006). The long-term effects of sulfur dioxide exposure are not clear, particularly the question whether sulfur dioxide actually causes lung disease. This in part is due to the difficulty in distinguishing the effects of this gas from those of other air pollutants.

Due to the close association of sources and environmental concentrations, the health effects from exposure to sulfur dioxide have been found to be associated with other air pollutants such as suspended particulate matter. Experimental studies on animals have demonstrated that the effects of sulfur dioxide may be enhanced when ultrafine particles are present (Amdur, 1986). This may be due to the formation of sulfuric acid on the surface of the inhaled ultrafine particles that are deposited deep into the lungs.

The evidence from population studies suggests that sulfur dioxide may be causally related to mortality at current ambient levels, but due to the lack of understanding of the interaction of sulfur dioxide with its co-pollutants, it is still unclear as to the degree to which sulfur dioxide is involved in this increase in deaths (USEPA, 2008). Intervention studies indicate that sulfur dioxide does play a major role. One such example was the sudden regulatory change in the sulfur content of fuel used by power stations and motor vehicles in Hong Kong in July 1990. This change in fuel quality resulted in a 50 per cent decline in ambient sulfur dioxide concentrations, with little change in ambient PM10 concentrations. Death rates for respiratory and cardiovascular diseases in Hong Kong were found to decline significantly after this intervention (Hedley et al., 2002). This Hong Kong case study suggests that a reduction in sulfur dioxide or other pollutants associated with sulfur-rich fuel leads to an immediate reduction in deaths (WHO, 2006).

It should be noted that daily and one-hour averages can conceal short-term sulfur dioxide peaks significantly greater than the calculated values. Annual averages can conceal many high short-term peaks, which may be more closely related with the health effects than the long-term average (National Environmental Health Forum, 1999). The USEPA has recently proposed a new national one-hour sulfur dioxide standard between 0.05 ppm and 0.10 ppm (USEPA, 2009). This USEPA standard is intended to protect against short-term exposures ranging from five minutes to 24 hours.

1.2.2 Effects on the ecosystem

Sulfur dioxide penetrates into the leaves of plants through the stomata, the microscopic pores on the surface of land plants utilised for gas exchange. At relatively short exposures to high concentrations of SO_2, plants can experience foliar necrosis (death of their leaves), chlorophyll destruction, and pigment formation. In addition, the cumulative nature of SO_2 means long term exposure can reduce plant growth and fruit (seed) yield.

Plants which do not have a cuticle or insoluble waxy membrane to limit their exchange with the ambient air (i.e. mosses and lichens) are very sensitive to increased levels of SO_2 in their surroundings, and are often selected as bio-indicators.

Sulphur dioxide and Nitrogen dioxide (NO_2) are the main precursors of acid deposition. Environmental damage can occur when the extra acid added to surface soil or water exceeds the capacity of ecosystems to accommodate it (DEWHA 2001).The effects of acid deposition range from the acidification of lakes and streams to the corrosion of buildings and the poisoning of living organisms.

Dry deposition of acid can also occur. If this occurs in areas where soils are poorly buffered, (unable to accept acid without change to acidity) soils can be easily acidified (DEWHA 2001).

1.2.3 Visibility impairment

As mentioned above, SO_2 can form secondary products (sulpfur trioxide [SO_3] and sulfates) that cause haze. Haze occurs when light is scattered or absorbed by gas or particles in the air. Haze can impair visibility under various meteorological conditions.

1.2.4 Dispersion of sulfur dioxide

When released into the atmosphere, SO_2 is slowly oxidised into sulfate and sulfuric acid. SO_2 and its oxidation products are removed from the atmosphere by wet and dry deposition. Despite these transformations and methods of removal, SO_2 can be transported over large distances; however concentrations reduce with time and distance. This means that air quality problems are often not confined to areas where the pollutant was originally emitted. Clean continental air contains less than 1 ppb of SO_2 (Eisinger and Burrows 1998).

1.3 Impact of sulfur dioxide on vegetation in the Kalgoorlie region

A study reported by KCGM (Kalgoorlie Consolidated Gold Mine) in 2007, summarised findings of annual vegetation monitoring from 1989 to 2007, to determine whether gaseous emissions of SO_2 had adversely affected vegetation in the vicinity of the Gidji roaster (KCGM 2007).

The vegetation monitoring, designed to comply with the Department of Environment and Conservation (DEC) licence conditions monitored the following:

(i) leaf sulfur contents of *Atriplex vesicaria* and *Eucalyptus clelandii,* from new growth, twice each year during Spring and Autumn
(ii) determined condition ratings of *Eucalyptus clelandii* and *Casuarina pauper,* twice each year during spring and autumn on a condition rating scale from one to five
(iii) provided colour photographs of *Eucalyptus clelandii* and *Casuarina pauper,* during autumn
(iv) measured soil pH during winter (July) and assessed the effects on native plants of sulfur dioxide exposure.

Total leaf sulfur content, expressed as percentage of the fresh weight (% F.wt) indicated a trend with leaf sulfur content for *Eucalyptus clelandii* increasing in value from 1989 to 2007, by 0.14% F.wt over the period. The lowest 75th quartile value was recorded in 1989 (0.08 % F.wt) with the greatest 75th quartile value (0.24% F.wt) recorded in 2006. Leaf sulfur content also increased for *Atriplex vesicaria* with the 75th quartile value in 1989 (0.32% F.wt) increasing to 0.4% F.wt in 2007.

Condition ratings, measured on a rating scale of one to five indicated an increase by two points between 1997 and 2004 with a subsequent decline from 2004 to 2007 of approximately one rating point. This decrease was attributed by KCGM to below average rainfall in 2007 (190mm) compared to previously recorded years (240 – 260mm).

2.0 AIR QUALITY STANDARDS

2.1 Environmental Protection Policy

Prior to 1988 there were no regulatory controls on air emissions in the Kalgoorlie-Boulder area, consequentially very high SO_2 levels were experienced by the local community which experienced significant health impacts (EPA 2004).

In 1988 an Environmental Protection Policy (EPP) was implemented for Goldfields residential areas to control the ambient air SO_2 concentrations. The EPP established air quality limits and, through license conditions, required industries to monitor SO_2 concentration levels to ensure the limits were being met.

Following a review of the policy, a new Environmental Protection (Goldfields Residential Areas) (Sulfur Dioxide) Policy and Regulations 1992 was established. This new policy extended the EPP area to include Coolgardie, Kambalda and the Kurrawang Aboriginal reserve. It also included maximum permitted sulfur dioxide concentrations (or limits), which were never to be exceeded together with a standard which was described as being not desirable to exceed. In recognition of the fact that industry would need time to modify its operations to meet the new requirements, a series of decreasing limits were prescribed which were intended to achieve the 1992 Goldfields EPP objectives within five years (EPA 1999).

In June 2003 a revised Environmental Protection (Goldfields Residential Areas) (Sulfur Dioxide) Policy and Regulations was gazetted. Under this revised EPP, maximum one-hour concentration limits progressively reduced from 0.35 ppm in 2003 to 0.25 ppm in 2005 (Table 1).

Furthermore, the 2003 EPP continued to set a one-hour “standard” (although no longer called such) of 0.2 ppm (Table 1). This desirable standard concentration was based on the NEPM one-hour ambient air quality standard of 0.2 ppm (EPA 2004). The EPP also established the maximum number of days this SO_2 concentration of 0.2 ppm could be exceeded before it must be reported to the Minister for the Environment. (Table 1). The objective and effect of this policy was to ensure that compliance with the NEPM goal for one-hour average SO_2 concentrations was achieved by 2008.

Both the 1988 and 1992 EPPs and associated regulations used the moving averages method to calculate standard and limit compliance. This method allowed the use of any 60 minute period in the calculation of concentrations (e.g. between 08:20 and 09:20 a.m.). All non-overlapping exceedences of the standard were counted (i.e. there could be more exceedence counted per day). Moreover, each exceedence of the standard occurring anywhere within the EPP area was cumulated and the total for the calendar year was used in assessing compliance within the allowance under the EPP.

The 2003 Environmental Protection (Goldfields Residential Areas) (Sulfur Dioxide) Policy and Regulations departed from the 1988 and 1992 method of assessment of the standards and limits set within the policy. The current method under this EPP uses “clock hours” to determine standard and limit compliance. In the ‘clock hour’ method, concentrations must be calculated as averages starting “on the hour” (e.g. 09:00 to 10:00 a.m.). The maximum number of times allowed for the desirable standard to be exceeded is now calculated as days per site, with each site allowed a specified number of days where the standard can be exceeded. Should the standard be breached more than one hour within the same calendar day at a given site, this will still only be counted as one exceedence day. The reason for this change in the 2003 EPP was to conform to the methodology of the National Environment Protection Council (Ambient Air Quality) Measure (NEPM) 1998.

For the years specific to this report, the corresponding reduction in concentrations for both limits and standards are provided in Table 1. Prior to 2003, the EPP limits and

standards were specified in micrograms per cubic metre at 0°C and 101325 Pa. For comparative purposes, all concentrations within this report have been converted into parts per million (ppm) with the original micrograms per cubic metre values shown in brackets.

Table 1 EPP one-hour limit and standard concentrations (ppm) and maximum number of exceedences of the standard permitted.

Year	Max SO_2 concentration (ppm) limit. Never to be exceeded	Desirable standard (ppm)	Max periods allowable for desirable standard to be exceeded
1999	0.49 (1400)	0.245 (700)	8 hours total per year
2000	0.49 (1400)	0.245 (700)	8 hours total per year
2001	0.49 (1400)	0.245 (700)	8 hours total per year
2002	0.49 (1400)	0.245 (700)	8 hours total per year
2003	0.35	0.2	3 days per site per year
2004	0.30	0.2	3 days per site per year
2005	0.25	0.2	2 days per site per year
2006	0.25	0.2	2 days per site per year
2007	0.25	0.2	2 days per site per year
2008 and each succeeding year	0.25	0.2	1 day per site per year

NOTE: Numbers in brackets are the equivalent concentration in micrograms per cubic metre as used in the 1992 EPP
(EPA 1993; 2004)

Compliance with key provisions of the EPP is required under licences to operate which deem it an offence, under section 58 of the *Environmental Protection Act 1986*, to contravene operational licence conditions. Licence conditions include adhering to maximum sulfur dioxide concentration levels prescribed in the EPP.

2.2 NEPM standards and goal

In 1998, the National Environment Protection Council (NEPC) made the National Environment Protection Measure (NEPM) for Ambient Air Quality which set out air quality standards applicable to all states and territories. The standards cover six criteria pollutants, including SO_2. These were the first national air quality standards established in Australia (NEPC 2007). The Air NEPM sets ambient air standards at concentration levels intended to protect human health, well being and local amenity. The goal of the Air NEPM is to ensure all NEPM standards are met to within the allowed exceedences within a 10 year time frame i.e. by 2008. To fulfil the monitoring requirements of the NEPM, the Department of Environmental Protection compiled a monitoring plan for Western Australia (DEP 2001) identifying five regions, including Kalgoorlie, in which monitoring would be required.

Implementation of the NEPM standards and goal is the responsibility of individual states and territories. (The NEPM does not approach the issue of regulating emissions). In WA this implementation will be achieved via the State Environmental (Ambient Air) Policy (SEP) which, at the time of writing, is in draft form (2009). In

relation to SO_2 in the Goldfields, the 2003 EPP was designed to provide consistency with the NEPM (and hence with any future State EPP or SEP for air) via identical standards for areas where people live from 2008 onwards, as described in the foregoing section. The EPP imposes a moderately higher limit for those same areas which is enforced via licences. The existence of this limit and the potential consequences for non-compliance provide a basis for confidence that the EPP standard and hence the NEPM goal for one-hour averaged SO_2 will be achieved. In the Goldfields context, with just three dominant emission sources well outside residential areas, compliance with the one-hour NEPM goal effectively ensures compliance with the 1 day and 1 year NEPM goals for SO_2. In summary, both the NEPM and EPP apply in the Goldfields with the latter designed to achieve the goals of the former in relation to SO_2.

The NEPM sets three standards for SO_2 (Table 2); an annual average, a 24-hour (daily) average, and an hourly average. All calculations are based on clock hours, calendar days and calendar years.

Table 2 NEPM standards and goals for sulfur dioxide

Averaging period	Maximum concentration	Goal Maximum allowed exceedences
One hour	0.20 ppm	1 day per year
One day	0.08 ppm	1 day per year
One year	0.02 ppm	none

The Air NEPM goal for SO_2, to be achieved by 2008, allows one exceedence of the maximum concentration per year for both the one-hour and 24-hour averaging period while the one-year standard must never be exceeded.

The Air NEPM is under review at the time of writing. Several jurisdictions around the world are currently reviewing SO_2 standards with the USEPA recently proposing a one-hour standard for concentrations of SO_2 in the atmosphere of between 0.05 ppm and 0.10 ppm.

3.0 SAMPLING LOCATION AND MONITORING METHOD

3.1 Monitoring station locations

The data used for this study were sourced from the monitoring station network which is owned and operated by KCGM in conjunction with BHP Billiton Nickel West and Kanowna Belle Gold Mines within the Goldfields EPP area. Seven stations are located within the city of Kalgoorlie-Boulder; BSY, HGC, AIR, KCY, KRH, MEX and WFY. An additional three monitoring stations are located outside of Kalgoorlie-Boulder in the Goldfields EPP areas, namely Kambalda town site (KAM), Coolgardie Primary School (CPS) and Kurrawang Aboriginal Reserve (KUR). One additional station, Satellite (SAT), is located outside the EPP area close to the Gidji roaster.

Site location and monitoring information is shown in Figure 2 and listed in Table 3.

Table 3 Kalgoorlie region SO_2 monitoring station information

Monitoring Station Site	Abbreviated Site Name	Duration	Method	Data logging
Kalgoorlie Airport (Hart Kespian Dr)	AIR	06/88 - present	Fluorescence	10 minute averages
Boulder Shire Yard (Forrest St Boulder)	BSY	06/88 - present	Fluorescence	10 minute averages
Coolgardie Primary School (Hunt St Coolgardie)	CPS	01/94 - present	Fluorescence	10 minute averages
Hannans Golf Course (Aslett Dr Kalgoorlie)	HGC	01/90 - present	Fluorescence	10 minute averages
Kambalda (Salmon Gum Dr Kambalda West)	KAM	01/94 - present	Fluorescence	10 minute averages
Kalgoorlie Council Yard (Hay St Kalgoorlie)	KCY	01/90 - present	Fluorescence	10 minute averages
Kurrawang Aboriginal Reserve (Sharpe Dr Kurrawang)	KUR	01/94 - present	Fluorescence	10 minute averages
Kalgoorlie Regional Hospital (Piccadilly St Kalgoorlie)	KRH	01/82 - present	Fluorescence	10 minute averages
Metals Exploration (Holmes St Boulder)	MEX	06/88 - present	Fluorescence	10 minute averages
Westrail Freight Yard (West Kalgoorlie Rd)	WFY	06/88 - present	Fluorescence	10 minute averages
Satellite (East of Goldfields Hwy)	SAT	05/89 - present	Fluorescence	10 minute averages

The Satellite station was installed by Kalgoorlie Consolidated Gold Mine (KCGM) to gauge SO_2 concentrations in the surrounds of Gidji gold roaster as part of the vegetation monitoring program. The monitoring station is located approximately 2 km northwest of Gidji roaster and 620 metres east of the Goldfields Highway.

3.3 Monitoring method

All of the monitoring stations use continuous fluorescence spectroscopy principles and are operated in accordance with AS 3580.4.1-1990 (direct reading instruments method). Fluorescence spectroscopy involves a stream of air being subjected to pulsed UV light at 215nm, which excites SO_2 molecules. When a molecule returns to its normal state, light is emitted. The amount of fluorescence is directly proportional to the concentration of SO_2 in air. The instruments provide an analogue signal which is logged and stored in digital form. Kalgoorlie industries have a joint arrangement for maintenance and calibration of instruments. Data are provided to DEC monthly as 10-minute averages in accordance with the requirements of the various industry license conditions.

3.4 Meteorological conditions

Situated in an arid climatic region, Kalgoorlie-Boulder has a dry climate with hot summers and cool winters. The average annual rainfall is approximately 260mm

which is fairly evenly distributed throughout the year. Significant variation exists however from year to year, with dry periods not uncommon.

The climate of Kalgoorlie-Boulder is strongly influenced by a band of high pressure known as the sub-tropical ridge. For much of the year this ridge is located to the south, allowing east to south-east winds to prevail. The ridge moves north during winter allowing the occasional cold front to pass over the Goldfields.

The most reliable rainfall occurs in winter from cold fronts arriving from the west, and cloud bands from the northwest. The wettest month during the study period was March with an average rainfall of 48.3mm (Figure 3). This was due in part to the 1999 and 2000 season when 197mm and 115mm of rain respectively, fell in March. Summer rainfall, arising from thunderstorms often produces heavy localised falls over short durations and although rare, decaying tropical cyclones, originating off the northwest coast can move through the Goldfields, producing heavy rains and occasional flooding. The highest annual rainfall occurred in 1992 with 530.8mm, resulting from a high number of thunderstorms and cloud bands during autumn and winter.

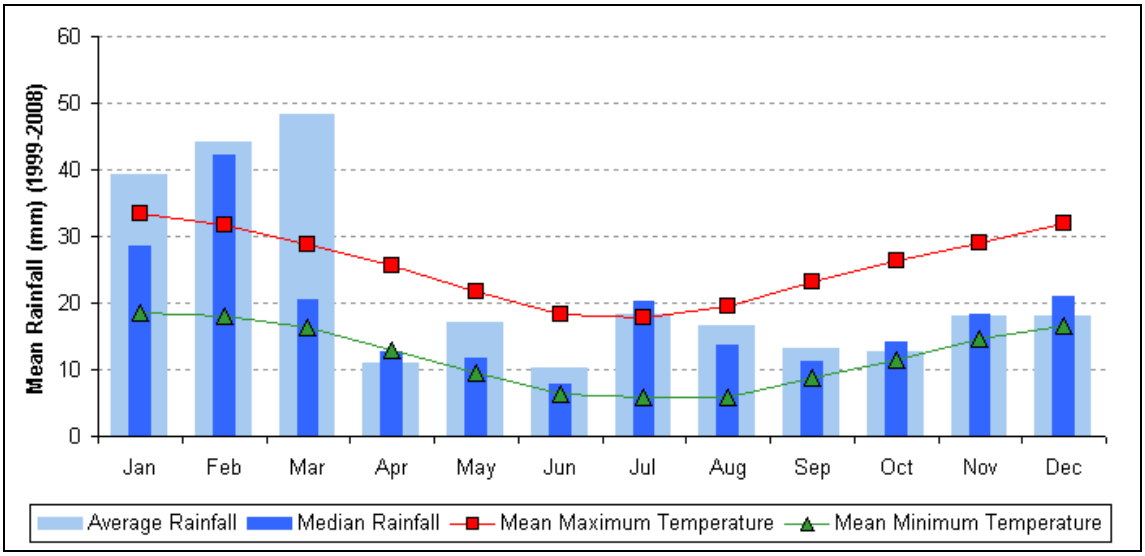


Figure 3 Kalgoorlie-Boulder Airport monthly meteorological statistics

A review of Kalgoorlie-Boulder Airport meteorological data for the period 1999 to 2008 indicates annual average annual temperatures and total annual rainfall to be consistent with long term averages (Table 4). Although the annual average rainfall amount from 1999 – 2008 is close to the long term average, the variability from year to year is quite high as it is typical for arid climates such as Kalgoorlie.

Table 4 Kalgoorlie-Boulder Airport meteorological data summary

Year	Mean Maximum Temperature (°C)	Mean Minimum Temperature (°C)	Annual Rainfall (mm)
1999	24.9	11.8	386.0
2000	24.0	11.2	446.0
2001	24.5	11.2	226.0
2002	26.1	12.2	188.2
2003	25.2	12.3	318.6
2004	25.2	11.9	279.6
2005	25.8	12.2	170.2
2006	25.6	12.2	190.2
2007	26.5	12.5	196.6
2008	25.5	12.4	266.6
1999-2008 Average	25.3	12.0	266.8
Long Term (1939-2008)	25.2	11.6	264.7

(Source: Bureau of Meteorology http://www.bom.gov.au)

Seasonal wind roses for Kalgoorlie were examined to determine whether a wind directional pattern was evident for the study area. Wind speed and directional data for the period 1999 to 2008 from the Metal Exploration monitoring station were used to create the wind roses shown in Figure 4. A trend depicting summer winds to prevail predominantly from east to southeast was evident while in winter, winds prevailed predominantly from a west to north-west direction.

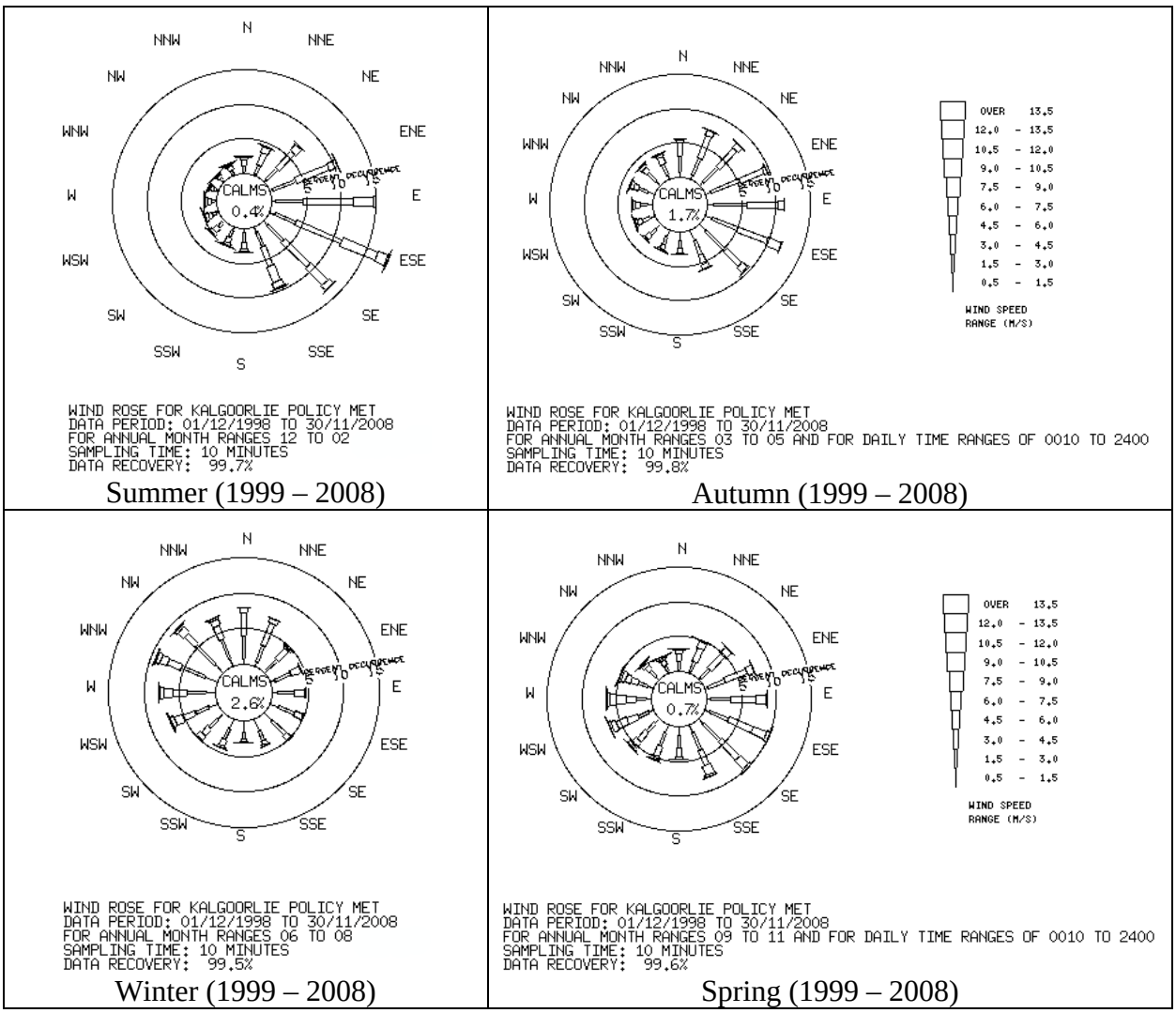


Figure 4 Seasonal wind roses for the Metal Exploration (MEX) monitoring station, 1999 to 2008.

4. ANALYSIS OF MONITORING DATA

Statistical analyses have been performed on concentrations of SO_2 measured at each monitoring station within the Kalgoorlie monitoring network from 1999 to 2008.

Data has been collated as daily, monthly, annual and time series plots to assist identification of ambient SO_2 concentration patterns and the dynamic behaviour of ambient SO_2 in the Kalgoorlie region.

The methods used for calculation of concentration averages under the 1992 and 2003 EPPs, which were in force for portions of the 1999-2008 study period, were outlined in section 2.1 and are explained in detail in Appendix 2. These methods have been used where appropriate for all calculations performed in this report.

4.1 Comparison to standards

All valid ambient SO_2 data for 1999 to 2008 were compared to the one-hour standards and limits set out in the relevant 1992 and 2003 EPPs and to the hourly, daily and annual NEPM standards.

4.1.1 Environmental Protection Policy (EPP)

Figure 5 shows the maximum one-hour SO_2 concentrations for all Kalgoorlie stations from 1999 to 2008, with the respective EPP limits and standards shown via shading. The SO_2 one-hour EPP limit was exceeded once between 1999 and 2008 at the CPS monitoring station in May 2005 with a one-hour concentration of 0.406 ppm (Table 5) compared to the limit of 0.25 ppm. Emissions were established to be from the Gidji Roaster facility operated by KCGM, leading to prosecution of the company. In the September 2005, the KUR monitoring station located to the south west of Kalgoorlie town site and Gidji roaster equalled, but did not exceeded, the EPP limit.

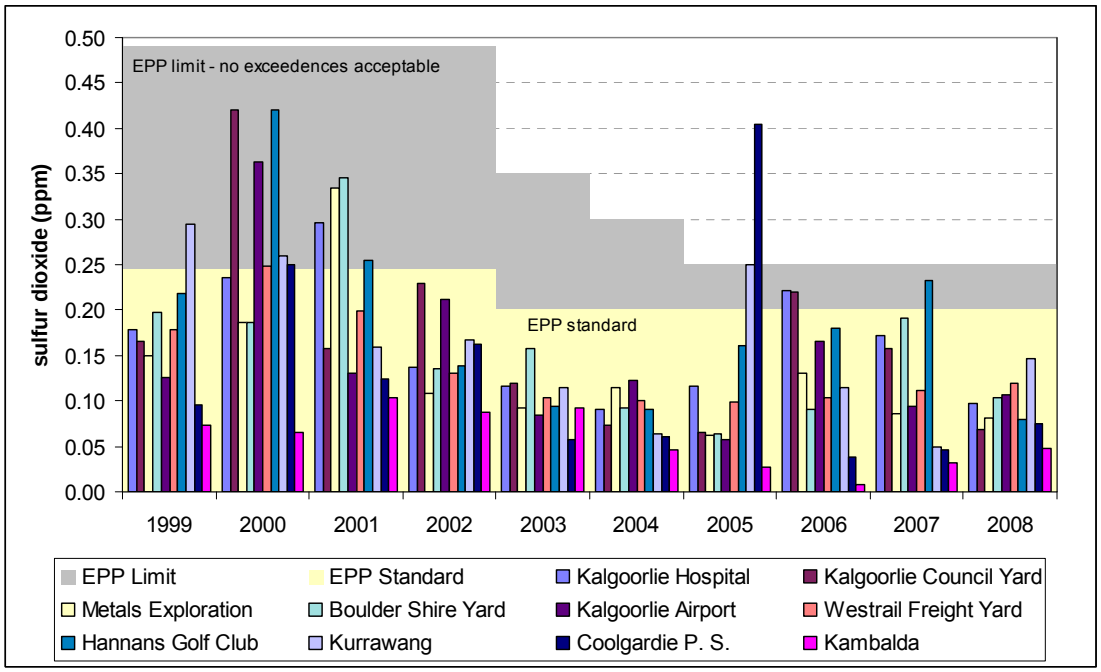


Figure 5 Maximum one-hour SO_2 concentrations for all Kalgoorlie stations from 1999 to 2008. Shading shows the EPP limit (grey) and standard (yellow) for the various years.

During the period 1999 to 2008, the only year during which the standard was exceeded for more than the allowed number of hours was 2000. In this year there were 11 one-hour periods greater than the standard (see Table 5) compared to the allowed 8 hours.

Table 5 Exceedences of the EPP within the policy areas (1999 – 2008)

Site	Date	1 hr average concentration (ppm)	Number of periods when the relevant standard was exceeded	Limit exceeded
KUR	21/01/1999	0.295	1 hour	
CPS	28/1/2000	0.250	1 hour	
KUR	21/03/2000	0.259	1 hour	
AIR	27/04/2000	0.294	1 hour	
AIR	4/08/2000	0.363	1 hour	
HGC	4/08/2000	0.420	2 hours	
KCY	4/08/2000	0.421	2 hours	
WFY	4/08/2000	0.248	1 hour	
AIR	3/11/2000	0.309	1 hour	
KCY	6/11/2000	0.278	1 hour	
MEX	10/05/2001	0.334	1 hour	
BSY	10/05/2001	0.346	1 hour	
HGC	18/12/2001	0.254	1 hour	
KRH	18/12/2001	0.296	1 hour	
CPS	27/05/2005	0.406	1 day	YES
KUR	2/09/2005	0.250	1 day	
KRH	11/02/2006	0.222	1 day	
KCY	11/02/2006	0.220	1 day	
HGC	22/05/2007	0.233	1 day	

4.1.2 NEPM standards

The Air NEPM was made in June 1998 and hence was in force for the full period of this study. As previously mentioned, the NEPM goal was to achieve the various standards to the extent specified (allowing for exceedences) within ten years (i.e. by 2008). In the following assessment of SO_2 measurements against the NEPM SO_2 standard, there is no implication that the NEPM goal (1 exceedence day per year at any place) should have been achieved in the EPP areas before 2008, or that compliance requirements for industries should have been anything other than those specified in the EPP.

The one-hour SO_2 averages from each monitoring station, from 1999 to 2008 were compared to the Air NEPM one-hour standard of 0.2 ppm. Table 6 lists the dates of each exceedence, with borders marking calendar years. The stations at which an exceedence occurred on a given date are identified by an entry in the station column of the time of the exceedence.

Table 6 Date and time of exceedences of the SO_2 one-hour NEPM standard in the Goldfields EPP areas (1999-2008)

Year	Date	Station									
		KRH	KCY	MEX	BSY	AIR	WFY	HGC	KUR	CPS	KAM
1999	21/01								15:00		
2000	28/01									01:00	
	21/03								06:00		
	27/04					03:00					
	04/08		17:00			17:00	17:00	16:00			
	03/11					21:00					
	06/11		03:00								
2001	09/05			24:00	24:00						
	18/12	10:00									
2005	27/05									10:00	
	02/09								12:00		
2006	11/02	18:00	18:00								
2007	22/05							10:00			

From table 6 it can be seen that the only year in which any individual monitoring station recorded more than one exceedence of the standards (being the NEPM goal to be achieved by 2008) was the year 2000. In that year, the AIR monitoring station recorded three exceedences and the KCY station two. The one-hour average at the KCY station on 6/11/2000 was 0.42 ppm, twice the NEPM standard but nevertheless considerably less than the very high concentrations measured in the preceding decades. The results in Table 6 and Figure 5 demonstrate the benefit of the acid plant at the nickel smelter and that industries are generally successful in keeping their plumes away from residential areas.

The 24-hour Air NEPM standard of 0.08 ppm was not exceeded at any station located within the EPP area at any time between 1999 and 2008 (Figure 6). The highest 24-hour average maximum occurred at the HGC station in 2000 with a value of 0.03 ppm, which is less than half the value of the 24-hour Air NEPM standard. The Air NEPM goal of one allowable exceedence per year from 1999 to 2008 was met at all sites within the EPP area.

The variation between the number of one-hour and 24-hour standards exceedences indicate one-hour values do not remain elevated for extended durations and at magnitudes significant enough to result in daily averages greater than the NEPM standard. This suggests that exceedences of the one-hour standards are caused by infrequent short-term events rather than an overall reduction in air quality.

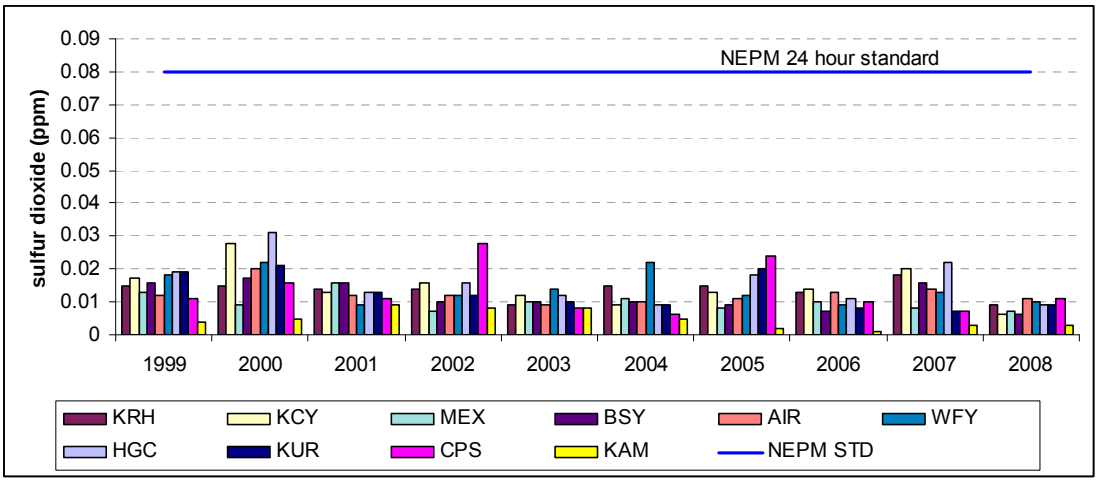


Figure 6 Maximum 24-hour SO_2 concentrations for all Kalgoorlie stations from 1999 to 2008 as compared to the NEPM 24-hour standard

In the Goldfields EPP area the annual SO_2 average remained significantly lower than the Air NEPM standard of 0.02 ppm with values ranging from less than 1% to 7% of the NEPM standard.

The highest yearly average of 0.0014 ppm was recorded at KUR in 2001 and is equivalent to 7% of the NEPM standard.

4.2 Statistics of one-hour and daily concentrations

For each year and station from 1999 to 2008 the following statistics were calculated from the daily maximum one-hour average and daily average data:

- maximum concentration of SO_2 during the year;
- second highest daily maximum concentration;
- 95th percentile – a value at which 95 per cent of the daily maxima fall below
- 90th and 50th percentiles.

All calculations were done as required for the 2003 EPP and the Air NEPM, as discussed in section 2 and Appendix 2.

Figure 7 and Figure 8 display the above statistics for all ambient monitoring stations located within Goldfields EPP area.

One-hour averages

For each site during the period 1999 to 2008, the statistics of daily maximum one-hour averaged concentration for each year were calculated, as shown in Figure 7.

The data indicate year-to-year variability in maximum one-hour SO_2 concentrations from 1999 to 2008. The same variability is also evident for the 2nd highest daily maximum concentration. From the 95th percentile and lower, SO_2 concentration values remain relatively constant for the entire study period.

The KAM station displays relatively lower SO_2 concentrations than that measured at the other stations.

Daily averages

For each site during the period 1999 to 2008, the daily averaged concentration for each day was calculated and statistics determined as shown in Figure 8.

The data indicates a similar lack of discernable trend to the maximum and second highest concentrations. Again as expected, the 90th percentile and below remain relatively constant with no major variations.

The KAM station has the lowest concentrations of SO_2 with values less then 0.01 ppm in any given year. This can be expected to be due to its considerable distance from the city of Kalgoorlie-Boulder, and the lack of influence from the SO_2 emitters there. From the NPI database, emissions of SO_2 by sources in Kambalda are metal ore mining and electricity supply, however; these release relatively small amounts (1,300 kg/year and 2.9 kg/year respectively).

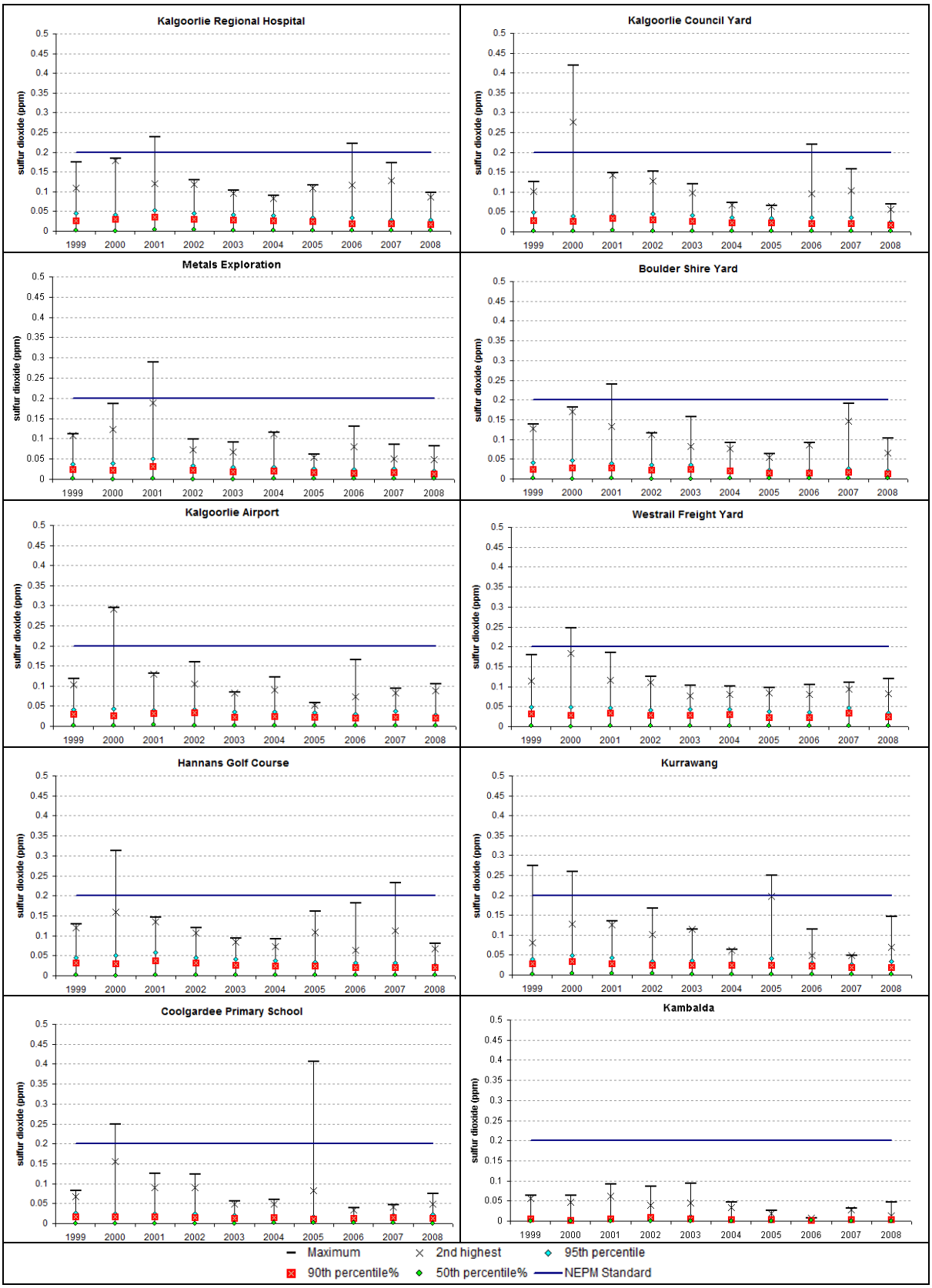


Figure 7 Annual statistics of one-hour averages of SO_2 for each EPP area monitoring site, 1999-2008

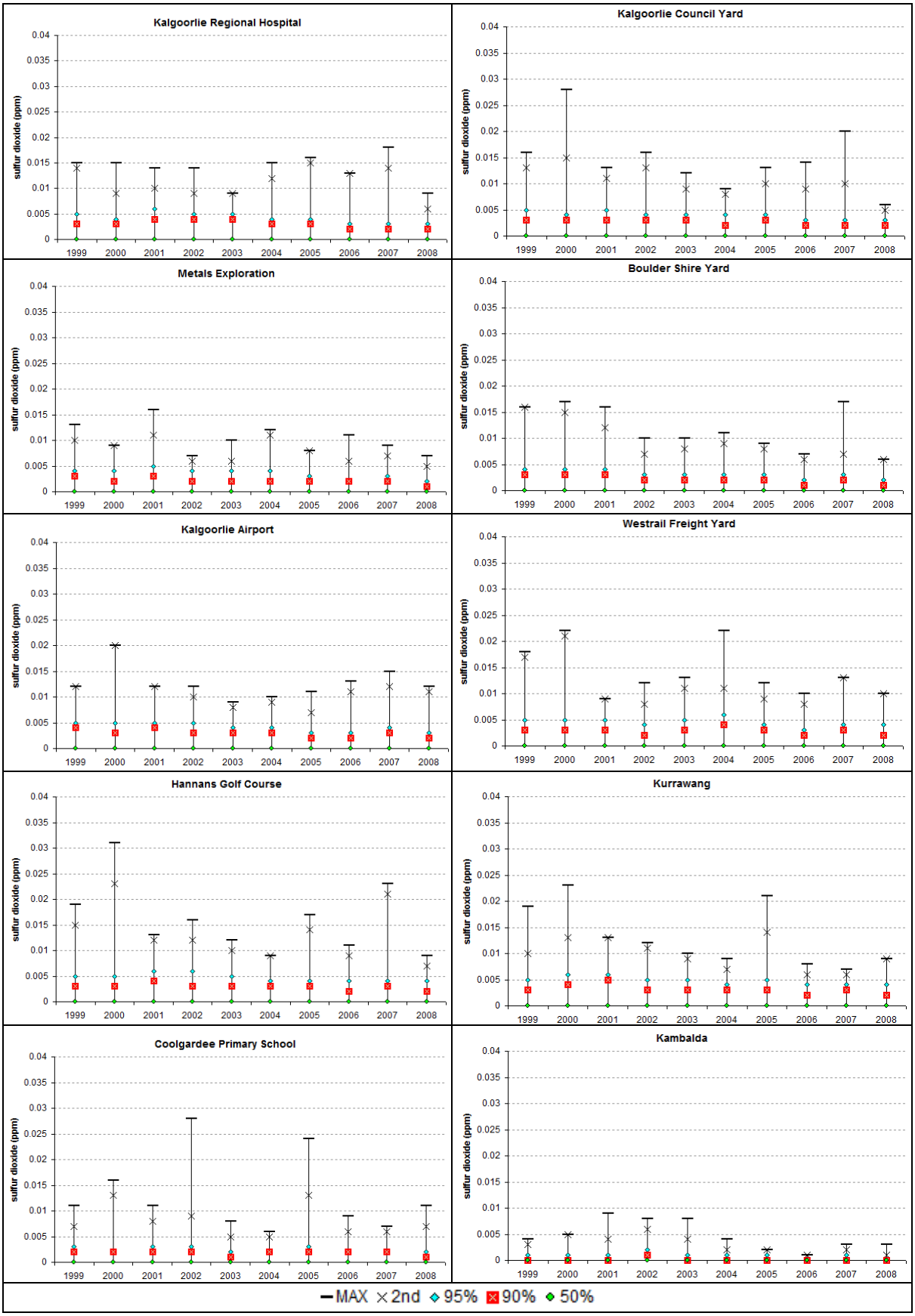


Figure 8 Annual statistics of daily averaged SO_2 for each EPP area monitoring site, 1999-2008

4.3 Annual Average and Monthly Variation

Annual average SO_2 concentrations at all sites located within the Goldfields EPP area were below 0.002 ppm during 1999 to 2008. This is less than 10 per cent of the Air NEPM standard for SO_2 of 0.02 ppm. KUR recorded the lowest annual concentration of less than 0.0005 ppm

For each month during the period 1999 to 2008, the maximum one-hour averaged concentration was calculated for all stations. Hence for any given calendar month, say January, there were 100 values of monthly maximum one-hour average concentrations (10 monitoring stations X 10 years). Statistics of concentrations for each of the 12 calendar months are shown in Figure 9.

A review of each of the monitoring years indicates SO_2 concentrations to vary monthly, however no common trends exist between years and no single year is representative for the 1999 to 2008 period.

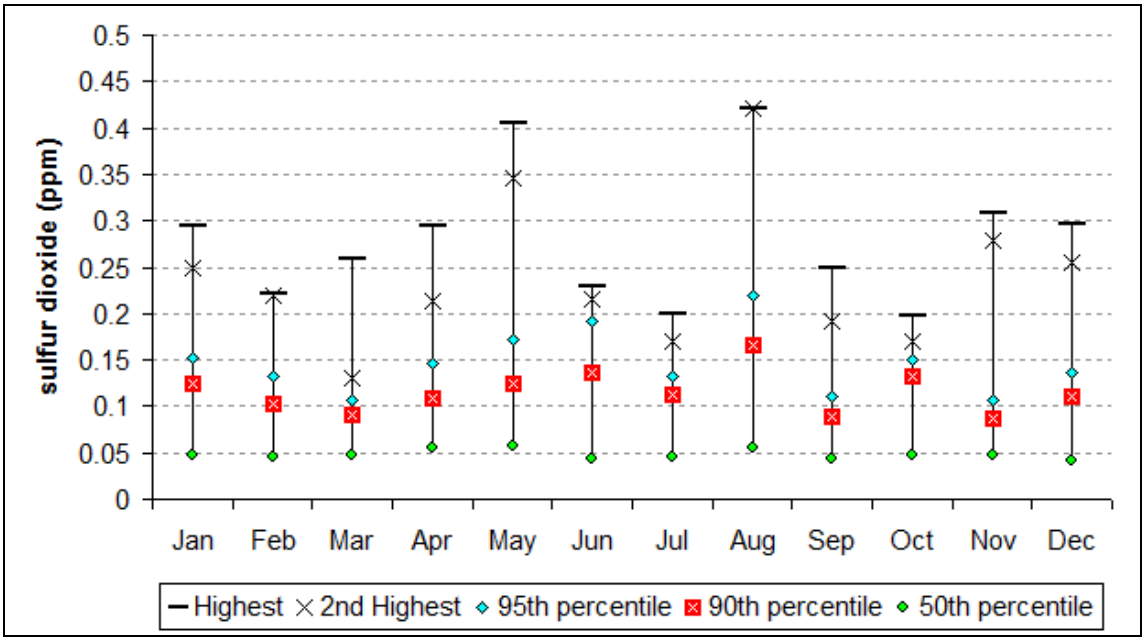


Figure 9 Statistics of monthly maximum one-hour average SO_2 concentrations for all monitoring stations (1999-2008)

4.4 Seasonal averages

For each year, one-hourly data was segregated into seasons and a seasonal average calculated. Figure 10 indicates the seasonal averages for all the Goldfields EPP monitoring stations.

The seasonal average among stations does not display reoccurring trends in seasonal concentration from year to year. This may be due to the major sources being located both north and south of the policy area. The peak average seasonal SO_2 concentration tends to shift between winter, summer and spring. This suggests that seasonal changes in climate may have little bearing on ambient SO_2 concentrations, with variation in SO_2 concentrations being more directly associated with emissions.

The summer season from 2000/1 to 2003/4 at the KUR monitoring station depicts the highest average seasonal SO_2 concentration. This is a similar trend to that at the WFY station which has a higher seasonal SO_2 average in summer, compared to winter. Spring and autumn SO_2 concentration typically sit between the low of winter and the high of summer, to form a yearly cyclical trend.

The higher summer SO_2 concentrations at KUR are presumably due to the wind directions from the south-easterly quadrant in summer that transports SO_2 emitted from the Kalgoorlie nickel smelter to the Kurrawang site.

From 1999 to 2008, the KAM station recorded its highest seasonal SO_2 average in winter albeit at a much lower concentration relative to the other stations. The lowest concentration occurs in either summer or spring. The KAM and KUR stations have opposite trends, that is, the highest SO_2 seasonal average at KAM occurs in winter, while at KUR it is in summer. This is expected given the predominant wind vectors within each season as shown in Figure 4.

The lack of cyclical trends at some of the monitoring sites may be due in part to the strategies put in place by the major emitters to manage their emissions. The relatively higher summer patterns at WFY and KUR however, indicate that some further assessment of management plans based on seasonal weather patterns may be needed.

While this seasonal analysis was done for the sake of thoroughness, a detailed analysis has not been carried out due to the complexity of factors and the time required.

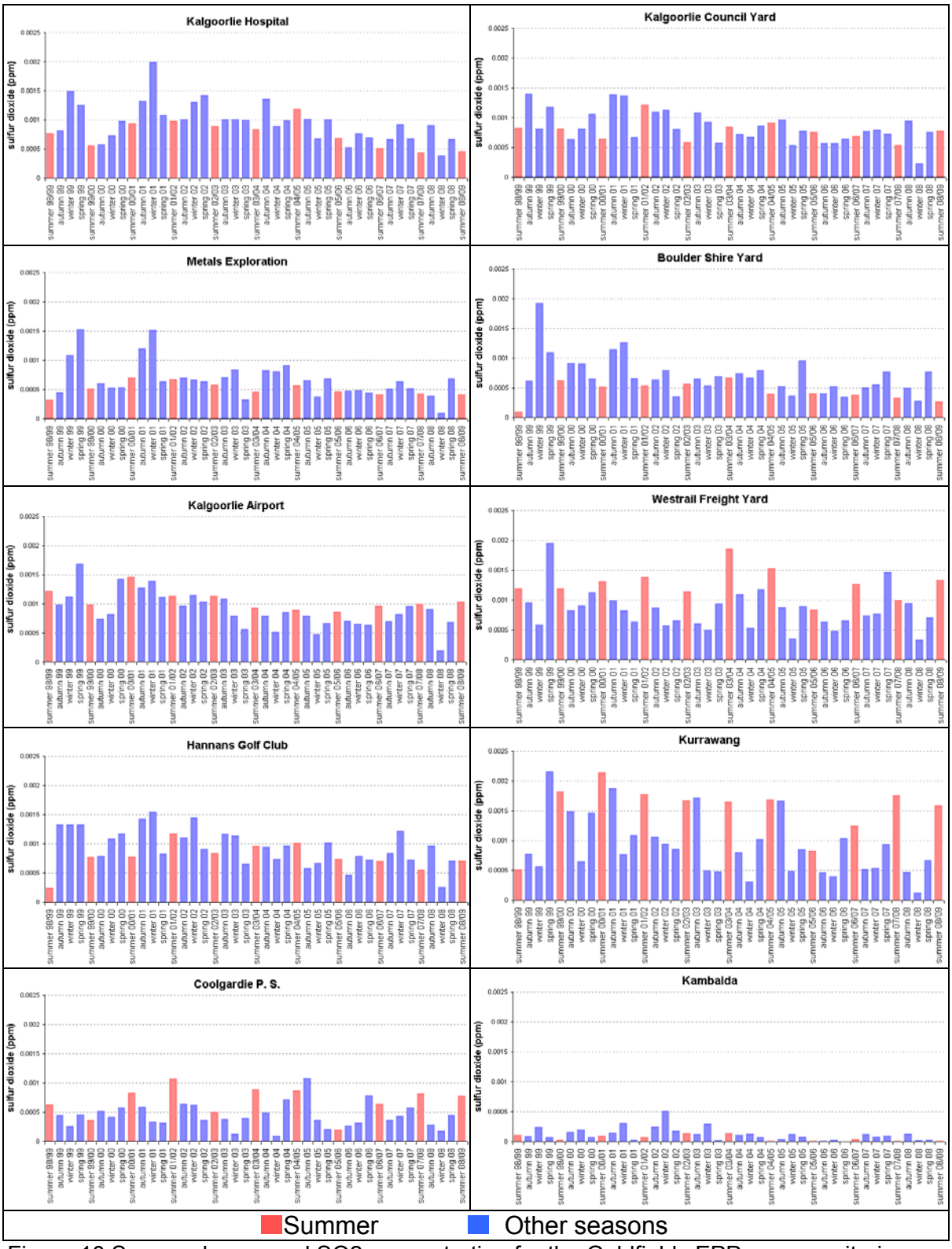


Figure 10 Seasonal averaged SO2 concentration for the Goldfields EPP area monitoring stations

4.5 Day vs. night differences in SO_2 concentrations

For the period 1999 to 2008, the SO_2 one-hour data was separated into day and night time values. Day-time was established as those hours from 07:00 to 18:00, and night-time from 19:00 to 06:00. Averages were calculated for each day and night time period and the results from the 10 Kalgoorlie stations located within the EPP area are plotted in Figure 11.

The night time SO_2 average concentration for Kalgoorlie (the average over seven stations) does not display any obvious times of the year when it is greatly higher or lower than the day-time values; however some, seasonal trends are discernable. Both day and night-time averages remain fairly constant for the whole year. On average for the 10-year period, night-time concentrations are approximately half those experienced during the day (Table 7). The highest SO_2 concentration was recorded during the day.

Table 7 Day time and night time SO_2 concentrations (1999-2008)

EPP site	10-year average day-time concentration (ppb)	10-year average night-time concentration (ppb)	Percentage Variation
KRH	1.201	0.617	51.0%
KCY	1.113	0.547	49.1%
MEX	0.888	0.393	44.3%
BSY	0.841	0.470	55.9%
AIR	1.114	0.720	64.6%
WFY	0.950	0.887	93.4%
HGC	1.247	0.582	46.7%
KUR	1.316	0.753	57.2%
CPS	0.582	0.428	73.5%
KAM	0.175	0.067	38.1%

At the WFY and to a lesser extent the CPS monitoring stations there are minimal difference between day and night-time values (day is 1.1 and 1.4 times higher on average respectively) during the study period.

While recording the lowest overall SO_2 concentrations, KAM station experienced the greatest variation with day-time concentrations generally 2.6 times the night-time concentrations over the study period.

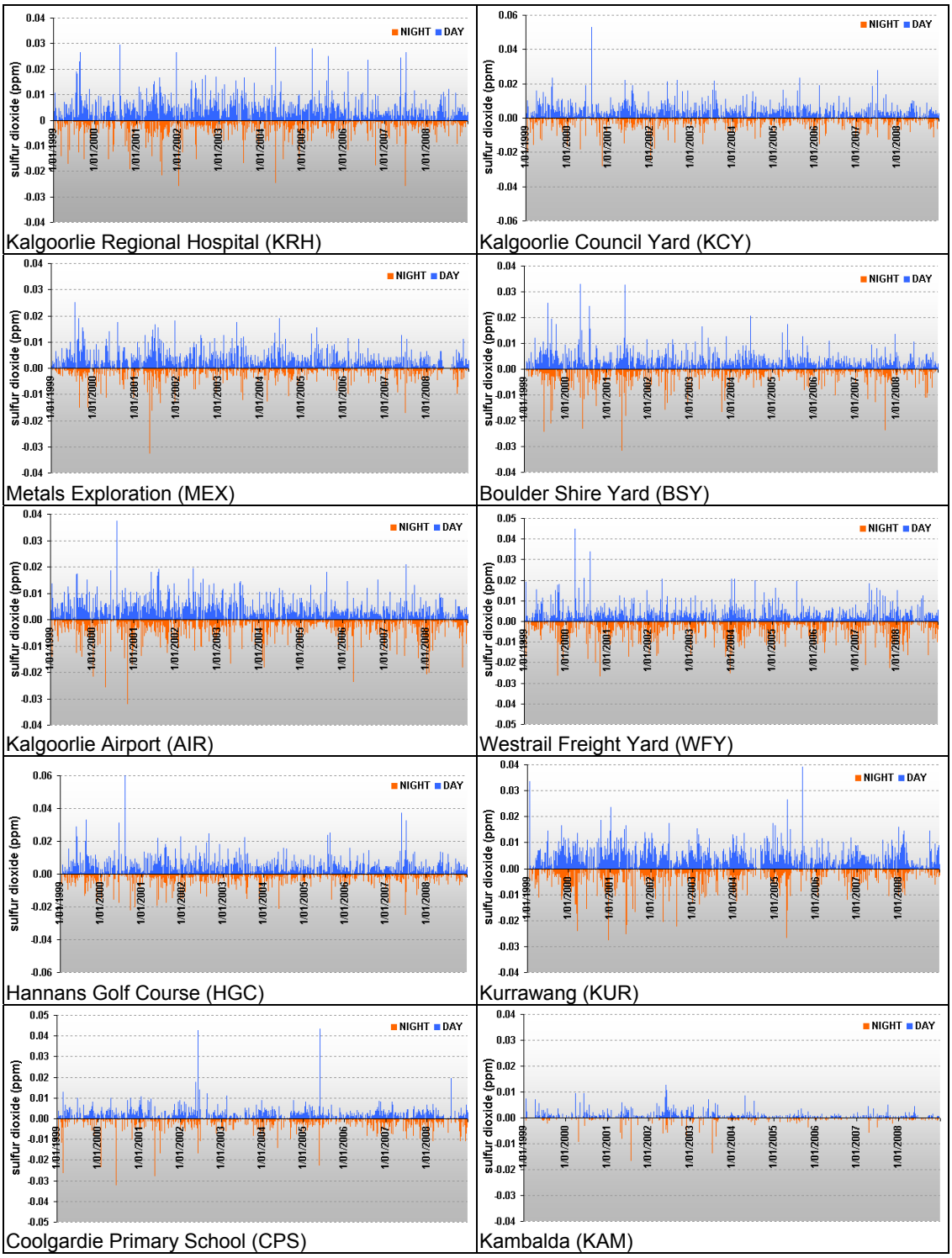


Figure 11 Day and night time averaged SO2 concentrations for the 10 stations located within the Goldfields EPP area average during the period 1999 to 2008
(note: night-time averages are shown as negative purely for display purposes only)

4.6 Back-trajectories

Wind characteristics are considered one of the best explanatory variables for determining air pollution sources. Wind direction indicates the trajectory or path of air pollutants from the source to the receptor while wind speed determines the distance from the source to the receptor and the time the ambient pollutants will take to reach the receptor.

Due to this strong relationship between wind and air pollution sources, wind trajectories or pathways were back-plotted for selected days when maximum SO_2 concentration exceeded the relevant EPP standards in place from 1999 to 2008. These back-trajectories are displayed in Appendix 1. Wind data for the plots were obtained from the MEX meteorological monitoring station and KNS sodar.

The three prominent SO_2 sources in the Kalgoorlie region are the Gidji roaster and Kanowna Bell Gold Mine (KBGM) roaster located to the north and the Kalgoorlie nickel smelter (KNS) located to the south of the city of Kalgoorlie.

Table 8 lists all exceedences within the EPP area and nominates the most likely source based on the back-trajectory analysis.

Table 8 EPP exceedences within the policy area during 1999 – 2008 with source

Site	Date	1 hr average concentration (ppm)	General wind direction	Likely SO_2 source
KUR	21/01/1999	0.295	Northerly	Gidji roaster and/or KBGM
CPS	28/1/2000	0.250	Easterly	KNS
KUR	21/03/2000	0.259	Northerly	Gidji roaster and/or KBGM
AIR	27/04/2000	0.294	Northerly	Gidji roaster and/or KBGM
AIR	4/08/2000	0.363	Northerly	Gidji roaster and/or KBGM
HGC	4/08/2000	0.420	Northerly	Gidji roaster and/or KBGM
KCY	4/08/2000	0.421	Northerly	Gidji roaster and/or KBGM
WFY	4/08/2000	0.248	Northerly	Gidji roaster and/or KBGM
AIR	3/11/2000	0.309	Southerly	KNS
KCY	6/11/2000	0.278	Northerly	Gidji roaster and/or KBGM
MEX	10/05/2001	0.334	Northerly	Gidji roaster and/or KBGM
BSY	10/05/2001	0.346	Northerly	Gidji roaster and/or KBGM
HGC	18/12/2001	0.254	Southerly	KNS
KRH	18/12/2001	0.296	Southerly	KNS
CPS	27/05/2005	0.406	Northerly	Gidji roaster
KUR	2/09/2005	0.250	Southerly	KNS
KRH	11/02/2006	0.222	Westerly	Indeterminate
KCY	11/02/2006	0.220	Westerly	Indeterminate
HGC	22/05/2007	0.233	Northerly	Gidji roaster and/or KBGM

4.7 Correlation between stations

The correlation of one-hour SO_2 data between all Goldfields EPP monitoring stations are given in Table 9. The closer to positive 1.0 the coefficient value is, the higher the similarity in trends between the two stations. If the correlation coefficient is close to negative 1.0, stations have completely opposite trends i.e. as one station experiences high SO_2 concentrations, the other has low concentrations. If the coefficient value is zero, then the two stations have no correlation and their trends are completely separate from each other.

The highest correlations are between the Kalgoorlie Airport (AIR) and the Kalgoorlie Council Yard Monitoring Station (KCY), namely 0.70, and between the Kalgoorlie Regional Hospital (KRH) and KCY monitoring stations, namely 0.72. The KCY and KRH stations are relatively close to each other at 1.5km apart, aligned north-east/south-west. Interestingly the AIR and KCY stations with an equally high correlation coefficient are double this distance apart (3.1 km) but again are aligned north east/south west. The other stations with a high positive correlation are the Boulder Shire Yard (BSY) and the Metals Explorations monitoring station (MEX), and KCY and Hannans Golf Club (HGC) each with a correlation coefficient of 0.70. The BSY and MEX stations are aligned north east/south west while the KCY and HGC stations are similarly aligned north to north west/south to south east. All of these monitoring stations are in alignment with the Gidji Roaster (north-east of BSY, MEX, KCY and HGC) and Kalgoorlie Nickel smelter (south to south-east of BSY, MEX, KCY and HGC) facilities.

The sites CPS, KUR and KAM are all outside the Kalgoorlie/Boulder EPP central boundary, and do not have significant correlations with the other seven sites within that boundary.

Table 9 Correlation matrix for all monitoring stations in the Goldfield EPP area

	KRH	KCY	MEX	BSY	AIR	WFY	HGC	KUR	CPS	KAM
KRH	1.00	0.72	0.56	0.37	0.50	0.24	0.60	0.07	0.07	0.08
KCY		1.00	0.38	0.25	0.70	0.31	0.70	0.07	0.06	0.06
MEX			1.00	0.70	0.40	0.15	0.34	0.09	0.03	0.09
BSY				1.00	0.26	0.10	0.22	0.06	0.01	0.07
AIR					1.00	0.26	0.53	0.07	0.03	0.06
WFY						1.00	0.39	0.07	0.06	0.00
HGC							1.00	0.11	0.12	0.05
KUR								1.00	0.14	0.00
CPS									1.00	0.00
KAM										1.00

4.8 Event potentials

While it is recognised that the current EPP and NEPM concentrate on the peak SO_2 values for each day at a particular site, it is fitting to also look at whether current data can also provide information on the potential for future SO_2 exceedences.

Figure 12 shows cumulated clock hour data for SO_2 concentrations greater than 0.05 ppm, 0.1 ppm and 75 per cent of EPP standard for the seven stations located within the city of Kalgoorlie-Boulder (BSY, KCY, AIR, HGC, KRH, MEX and WFY). The two lower figures were included to explore the recently proposed USEPA one-hour standard for concentrations of SO_2 in the atmosphere of between 0.05 ppm and 0.10 ppm. The highest is 75 per cent of the relevant EPP standard existing at the time and is seen to be indicative of a 'near miss' event. This 75 per cent value equates to 0.184 ppm for 1999 to 2002 and 0.15 ppm for 2003 to 2008.

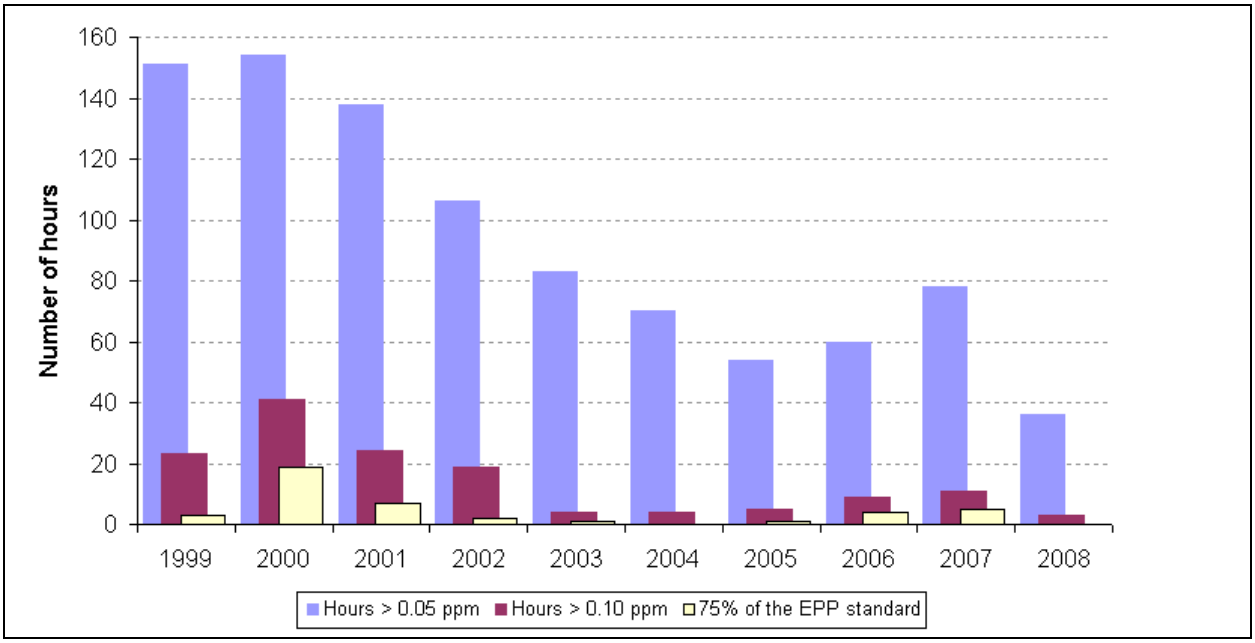


Figure 12 The number of clock hours when SO_2 exceeded indicated concentrations

The current Goldfields EPP and the Air NEPM determine exceedences based on the number of exceedence days per monitoring site without any regard to how many times the hourly standard is exceeded within that day. Notwithstanding, Figure 12 has been plotted using cumulated hourly data for all seven stations as each hourly concentration greater than the stipulated value has the potential to cause an exceedence day even though any particular exceedence may occur on the same day and at the same site as another.

The concentrations above 75 per cent of Goldfields EPP standard remained generally steady averaging less than five per year for 1999 and 2001 to 2008. In 2000, there were 19 times when this concentration was exceeded. Of these, 11 were actual exceedences of the 1992 EPP one hour standard of 0.254 ppm and have been discussed elsewhere in this document.

It is notable that the number of hours greater than 0.10 ppm (or 50 per cent of the NEPM standard) declined markedly from 19 hours in 2002 to four hours in 2003. There were no EPP or NEPM exceedences in either 2002 or 2003. A possible reason for this drop may be the improvement of emissions management of the significant sulfur dioxide emitters both leading up to and after imposition of the lower standards and limits mandated by the 2003 Goldfields EPP which came into affect on 18 March 2003.

There has been a generally steady decline in the number of hours exceeding 0.05 ppm from a peak of 154 hours in 2000 to a low of 36 hours in 2008.

The number of hourly exceedences of each prescribed concentration has generally declined over the period 1999 to 2008.

4.9 Comparison to other Australian monitoring sites

Kalgoorlie/Boulder EPP area stations (AIR, BSY, HGC, KCY, KRH, MEX and WFY) were compared to monitoring sites in South Australia, Queensland and Western Australia for one-hour and 24-hour daily maximum and annual average concentrations of SO_2 (Table 10).

Monitoring sites include Port Pirie in South Australia and Mount Isa, Queensland. All data being compared within Table 10 comes from monitoring sites representing residential areas or other sensitive receptors. These cities both contain large scale mining and smelting operations. Port Pirie contains one of the world's largest lead smelters and metal refineries while Mount Isa, located in arid north-west Queensland, is one of the largest copper mining and smelting operations in the country.

Table 10 also includes DEC air quality monitoring sites at Hope Valley (Industrial buffer zone), Rockingham (urban/residential coastal), Wattleup (Industrial buffer zone) and South Lake (urban/residential). These sites are located in the vicinity of the Kwinana Industrial Area (KIA) and are monitored under the Perth Metropolitan Ambient Air Quality Monitoring Program. Historically, KIA has had high SO_2 emissions from the combustion of sulfurous fuels at local alumina, nickel and oil refineries and a power station.

Tabled data indicates SO_2 ambient concentrations in Port Pirie and Mount Isa to be consistently greater than those recorded in the Kalgoorlie/Boulder EPP area.

The highest one-hour maximum concentration recorded from 2002–2005 was measured at Mount Isa in 2002 with a value of 1.254 ppm. This is 7.5 times greater than the one-hour average for Kalgoorlie in the same year and 1.3 times greater than the next highest one-hour average, recorded at Mt Isa in 2005. The highest one-hour maximum concentration is also over 6 times greater than the NEPM standard of 0.2 ppm.

The highest 24-hour average occurred in 2004 at Mount Isa with a value of 0.1 ppm. This value was 4.5 times greater than that recorded in Kalgoorlie during the same year and 25 per cent greater than the NEPM standard of 0.08 ppm.

For both the 24-hour maximum and annual SO_2 averages, Mount Isa was ranked the highest for most years.

The comparison presented in Table 10 indicates SO_2 emissions in Port Pirie and Mount Isa to be consistently and significantly greater than those recorded in the Kalgoorlie/Boulder EPP area.

Table 10 Comparison of average SO_2 concentrations (ppm) in Kalgoorlie with other Australian sites, 2002 to 2005.

		NEPM Standard	Kalgoorlie - WA[1]	No of NEPM exceedences Kalgoorlie - WA[1]	Port Pirie - SA[2]	Mount Isa - QLD[3]	Hope Valley - WA[4]	Rockingham - WA[4]	Southlake - WA[4]	Wattleup - WA[4]
		ppm	ppm		ppm	ppm	ppm	ppm	ppm	ppm
2002	**1-hour**	0.20	0.167	-	0.656 ↑	1.254 ↑	0.058 ↓	0.035 ↓	0.043 ↓	0.081 ↓
	24-hour	0.08	0.028	0	0.05 ↑	0.081 ↑	0.007 ↓	0.006 ↓	0.006 ↓	0.008 ↓
	1-yr	0.02	0.001	0	0.01 ↑	0.009 ↑	0.001	0.001	0.001	0.001
2003	**1-hour**	0.20	0.158	-	0.487 ↑	0.658 ↑	0.06 ↓	0.026 ↓	0.038 ↓	0.062 ↓
	24-hour	0.08	0.014	0	0.095 ↑	0.093 ↑	0.006 ↓	0.005 ↓	0.006 ↓	0.006 ↓
	1-yr	0.02	0.002	0	0.008 ↑	0.007 ↑	0.001	0.001	0.001	0.001
2004	**1-hour**	0.20	0.121	-	0.44 ↑	0.888 ↑	0.061 ↓	0.039 ↓	0.042 ↓	0.076 ↓
	24-hour	0.08	0.022	0	0.051 ↑	0.100 ↑	0.009 ↓	0.006 ↓	0.005 ↓	0.009 ↓
	1-yr	0.02	0.001	0	0.008 ↑	0.006 ↑	0.001	0.001	0.001	0.001
2005	**1-hour**	0.20	0.405	2	0.721 ↑	0.964 ↑	0.074 ↓	0.041 ↓	0.046 ↓	0.12 ↓
	24-hour	0.08	0.024	0	0.072 ↑	0.091 ↑	0.011 ↓	0.009 ↓	0.007 ↓	0.014 ↓
	1-yr	0.02	0.001	0	0.008 ↑	0.009 ↑	0.001	0.001	0.001	0.001

↑ A value higher than that measured in Kalgoorlie ↓ A value lower than that measured in Kalgoorlie

1 Data sourced from KCGM Kalgoorlie EPP monitoring stations (10 monitoring stations, AIR, BSY, HGC, KCY, KRH, MEX, WFY, KUR, KAM, CPS)
2 EPA SA, 2006
3 Neale, 2005
4 Data sourced from 2006 WA Air Monitoring Report, Department of Environment and Conservation

4.10 Radiello study

A monitoring program for SO_2 was conducted by DEC from 22 December 2008 to 16 March 2009 outside Goldfields EPP areas in efforts to determine possible SO2 concentrations experienced by people living outside the EPP areas and those transiting through the region.

This SO_2 monitoring program utilised a passive diffusive method of air sampling using Radiello sampling tubes. Radiello tubes consist of a cylindrical semi – permeable diffusive body that allow a constant gas exchange rate. These tubes are fitted with a cartridge which absorbs SO_2. The diffusive body is 60mm in height and 16mm in diameter and is made of microporous polyethylene, 1.7mm thick and having a porosity of 25 ± 5 µm. The diffusive path length is 18mm. The absorbing cartridge is also made of microporous polyethylene and coated with triethanolamine (TEA) and is 60mm by 4.8mm. SO_2 is adsorbed onto the TEA as sulphite or sulphate ions.

The Radiello sites were commissioned at six locations in the Kalgoorlie-Boulder region. Each site was fitted with a radiello sampler which was deployed for seven days, thereby providing a weekly average SO_2 concentration in locations outside EPP areas, where a number of complaints were received regarding SO_2 plumes.

While there is no seven day standard applicable to SO_2 within Western Australia, the passive samplers used in this study were deployed weekly to allow sufficient time for the samplers to uptake enough SO_2 for adequate analysis.

Sites were commissioned to the north, north-west, west, south and south-east of the Kalgoorlie town site as illustrated in Figure 2. The sites selected and commissioned were, East Kalgoorlie Primary School, Goldfields Hwy, Broad Arrow, Ora Banda, Black Flag and Kalgoorlie Airport.

Site 1.*East Kalgoorlie Primary School (E355070 N6597412)*

The East Kalgoorlie Primary School site is located to the east of Kalgoorlie in Williamstown and is within the Kalgoorlie/Boulder EPP area. This site has been commissioned to address local complaints received regarding emissions from the Gidji roaster stack.

Site 2.*Goldfields Highway (E350069, N6615039)*

The Goldfields Highway site is located 19km north of Kalgoorlie and is outside the defined EPP areas. This site is 2km east of the Gidji Roaster, the source of multiple complaints, particularly from vehicles utilising the highway or parking bay. The proximity of the monitoring site to the Gidji roaster is shown in Figure 13.

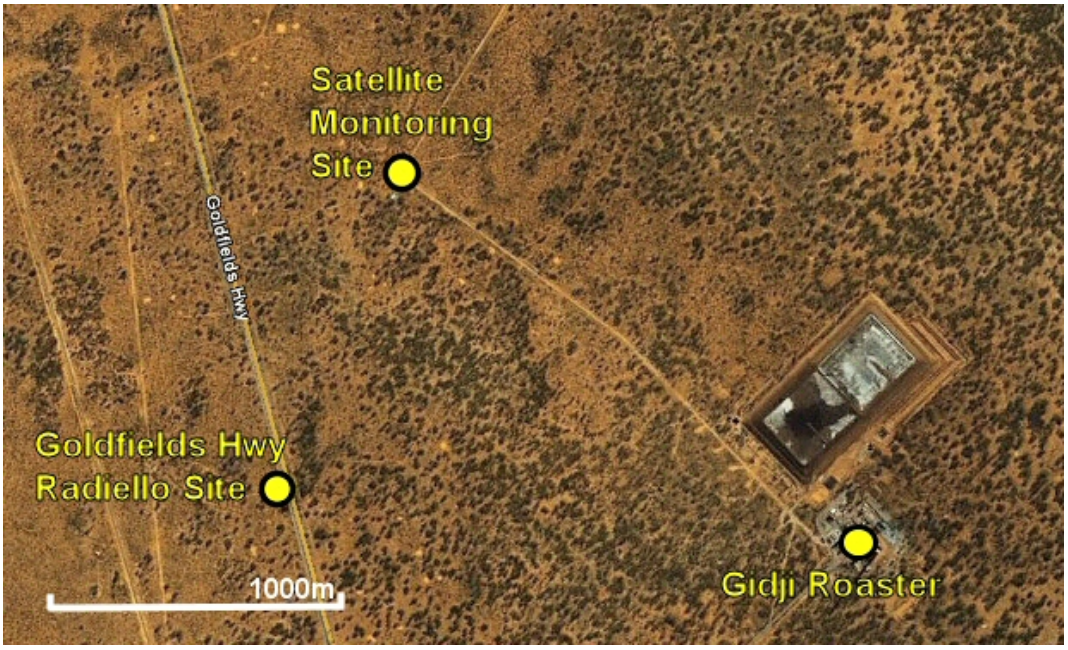


Figure 13 Goldfields Hwy site in relation to the Gidji roaster and the Satellite monitoring station

Site 3. *Broad Arrow (E339651, N6630312)*

The Broad Arrow site is located further north of the Goldfields Hwy site, adjoining the Goldfields Hwy and is also outside the defined EPP areas.

Land use surrounding the site includes a car park for the nearby Broad Arrow pub, a few residences and remnant bushland.

Site 4. *Ora Banda (E313658, N6637869)*

The Ora Banda site is similar to the previous site and is located outside the Ora Banda tavern. This station is the most distant from the Roaster and Kalgoorlie town site. The site is far outside the defined EPP areas

Site 5. *Black Flag (E329595, N6617647)*

The Black Flag site as its name describes is located near the Black Flag homestead and is outside the defined EPP areas. The surrounding land is predominantly remnant bushland.

Site 6. *Kalgoorlie Airport (E352564, N6593303)*

The airport site is located within the town of Kalgoorlie at the domestic airport. This is also the location of one of the 10 continuous SO_2 policy area samplers (AIR). The airport is located to the south-east of town, and is surrounded by residential land to the north side, and a remnant bush block to the south.

This site was selected as the control site as the SO_2 continuous monitoring station also located at the airport would allow for comparison of SO_2. During the period of this study, the airport site failed to record any significant SO_2 concentrations at either the continuous monitor or the Radiello site. The concentrations of six out of the 11 Radiellio samples obtained at this site were below the laboratory's limit of reporting

(LOR) with the remainder very close to the LOR so no meaningful comparisons could be made.

Distances between SO_2 radiello sites are presented in Table 12.

Table 12 Distance (km) between SO_2 radiello sites in Kalgoorlie region

Site	BF	EK	BA	OB	KA	GR	TC
GH	20.8	18.5	18.6	42.7	22	2	18.6
BF		32.5	15.8	25.6	33.4	22.4	31.3
EK			36.3	57.9	4.8	18.2	2.0
BA				26.9	39.3	19.5	36.1
OB					59.3	44.5	57.2
KA						21.6	3.5
GR							18.5

Legend:
GH: Goldfields Hwy, BF: Black Flag, EK: East Kalgoorlie Primary School,
OB: Ora Banda, BA: Broken Arrow, KA: Kalgoorlie Airport, GR: Gidji Roaster
TC: Town Centre

Overall, 69 exposed samples were obtained across the 6 monitoring sites from 22 December 2008 to 16 March 2009 (Figure 14 and Table 13). Of the weekly concentrations obtained, 26 per cent were below the practical quantification limit (PQL). The PQL was <0.0006 ppm. In instances where concentration values were reported as the PQL, these were halved for the purpose of calculating averages.

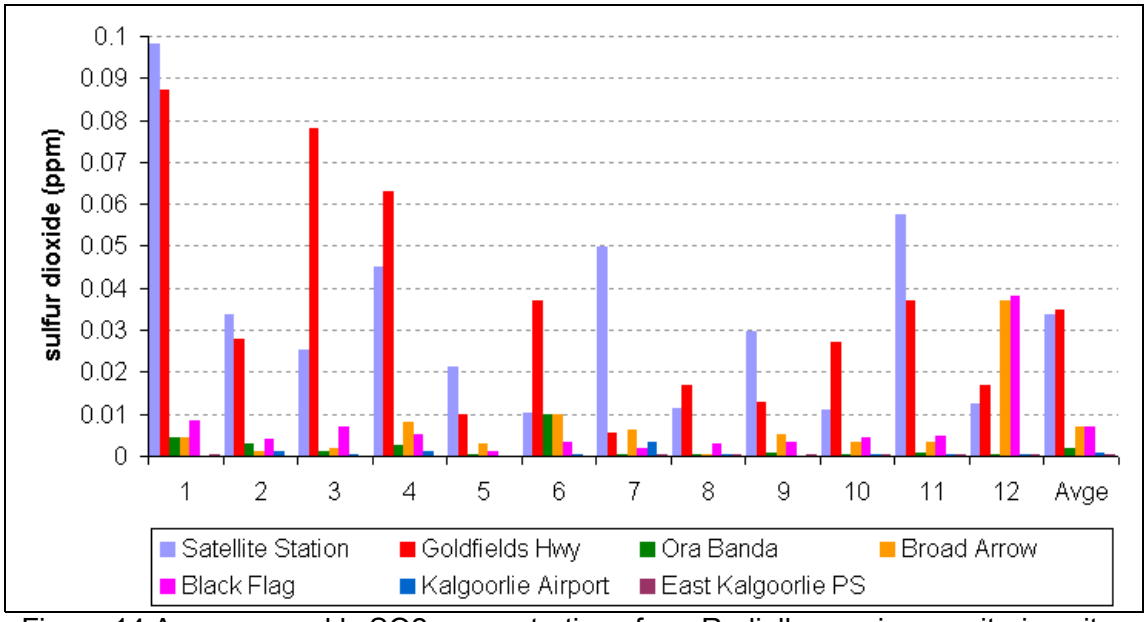


Figure 14 Average weekly SO2 concentrations from Radiello passive monitoring sites and the Satellite continuous monitor (22/12/2008 – 16/03/2009)

The Radiello sites within the Kalgoorlie town site (Kalgoorlie Airport and East Kalgoorlie Primary School) recorded the lowest weekly concentration values at 0.0081 ppm and 0.0025 ppm respectively. On seven occasions, these sites recorded concentrations below the PQL. Ora Banda and Broad Arrow sites also recorded values less than the PQL.

Table 13 Minimum, maximum and average weekly SO_2 concentrations at Radiello passive monitoring stations

Radiello Passive Monitoring Station	Min Weekly SO_2 Concentration (ppm)	Max Weekly SO_2 Concentration (ppm)	Average Weekly SO_2 Concentration (ppm)
Goldfields Hwy	0.0056	0.087	0.0350
Ora Banda	0.00025	0.010	0.0020
Broad Arrow	0.00025	0.037	0.0070
Black Flag	0.00099	0.038	0.0071
Kalgoorlie Airport	0.00005	0.0032	0.0007
East Kalgoorlie PS	0.00005	0.00037	0.0002

The Goldfields highway site recorded the three highest seven-day averaged concentrations of 0.087 ppm, 0.078 ppm and 0.063 ppm. Coincident seven-day averaged concentrations calculated from data from the nearby Satellite monitoring station are generally consistent in magnitude with those from the Goldfields highway Radiello site (see Figure 14), with week to week variability most likely due to changes in dominant wind direction. The Black Flag site recorded the fourth highest weekly concentration of 0.038 ppm. The Goldfields Hwy site recorded the highest overall average concentration during the study period of 0.0350 ppm.

Results from the Goldfields Radiello monitoring program show that weekly averaged SO_2 concentrations recorded at the Highway sampling site are much higher than at other Radiello sampling sites during the 12 week program. These results are consistent with complaints received from people travelling or parked along the highway and suggest that further investigation is warranted. A preliminary analysis is given in the next section.

4.11 Plume impacts on the Goldfields Highway

As mentioned above there have been multiple complaints particularly from motorists driving along the highway or using the parking bay adjacent to the Gidji Roaster.

Wind roses for each weekly period when Radiello sampling was taking place are displayed in Figures 15. The wind roses show winds mostly coming from an arc NE to SSE, confirming the likelihood that the plume from Gidji commonly crosses the highway at this time of year somewhere along a strip of highway several kilometres long. It is well established that a plume like this can and does mix to ground quite close to the roaster during daytime, particular during hotter months as in this measurement program.

Figures 16 tonnage gives the throughput of the Gidji Roaster during the Radiello program, showing that the roaster was operating throughout.

Although there may have been occasions where a person was effected by the plume for an extended period of time, the most likely circumstance is motorists encountering the plume as they drive, which would be a short event (a few minutes) in the course of traversing the width of the plume. Accordingly it is appropriate to consider the

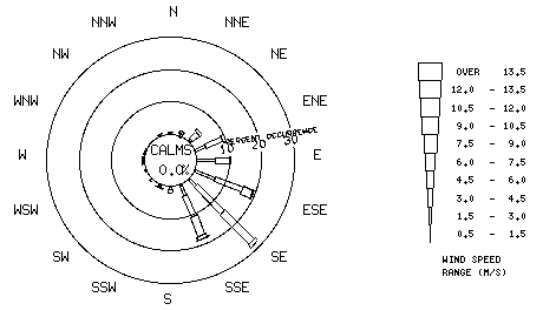
magnitude of short term high concentrations that might occur rather than considering one-hour averages (or longer averaging times).

It is obvious from Figure 13 that the Satellite monitoring site is well located with respect to the prevailing winds seen in Figure 15 and that it will measure SO_2 concentrations that are representative of those experienced at locations on the highway at roughly similar distances from the roaster. So we can use the statistics of 10-minute concentrations from this site as being representative of a site on the highway. Table 14 provides statistics for the period of the Radiello program. The table gives, in addition to the maxima, the number of times that the 10-minute averaged concentration exceeds 0.7, 0.35, 0.25 and 0.18 parts per million. The last two of these are the NSW assessment criterion for sensitive receptors and the World Health Organisation guideline respectively. The number of exceedences is used to calculate a percentage probability of exceedence in the next column of Table 14, i.e. the percentage of time during the Radiello program that the measured 10-minute average would equal or exceed the value in question.

Table 14 Satellite site SO_2 statistics during the period passive samplers were in operation 22/12/2008 – 16/03/2009

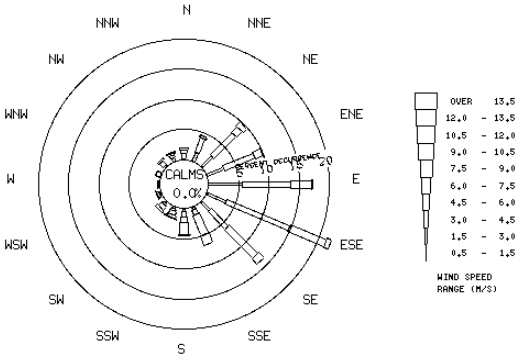
Concentrations	Number of 10 minute periods greater than indicated concentration	Percentage (%)
> 0.18 ppm	614	5.0
> 0.25 ppm	502	4.1
> 0.35 ppm	390	3.2
> 0.70 ppm	187	1.5
Total number of records	12240	-

Table 14 indicates the probability of exceeding four concentration levels at a single fixed location somewhere on the highway adjacent the roaster. (Consider it to be a monitoring station like the Satellite station somewhere on the highway near the smelter – there would be flexibility in choosing its location, but once installed it does not move.) At a particular point in time the roaster plume might be crossing the highway to the north or south of the fixed location and causing high concentrations on the highway that would not be recorded at the fixed location. But a motorist traversing the stretch of highway would (quite likely) experience that plume at its point of crossing. (The “quite likely” qualification relates to the fact that plumes on warm/hot days also move up and down, such that the plume is not always touching the ground at a particular downwind distance). Consequently the probabilities of a motorist encountering the concentrations assessed in Table 14 are greater than those presented in Table 14 for a fixed location. More detailed analysis and possibly modelling would be required to quantify these probabilities.



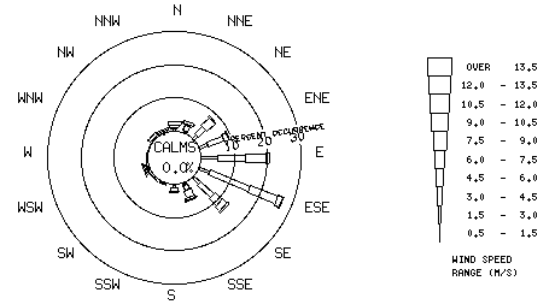
WIND ROSE FOR KALGOORLIE POLICY MET
DATA PERIOD: 22/12/2008 TO 29/12/2008
FOR DAILY TIME RANGES OF 0010 TO 2400
SAMPLING TIME: 10 MINUTES
DATA RECOVERY: 100.0%

Week 1



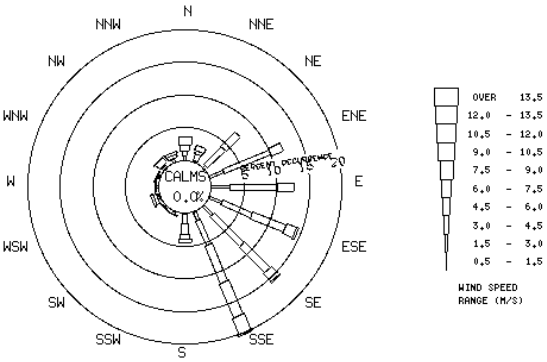
WIND ROSE FOR KALGOORLIE POLICY MET
DATA PERIOD: 29/12/2008 TO 05/01/2009
FOR DAILY TIME RANGES OF 0010 TO 2400
SAMPLING TIME: 10 MINUTES
DATA RECOVERY: 99.5%

Week 2



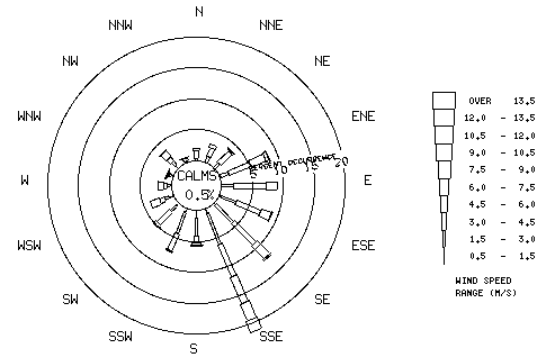
WIND ROSE FOR KALGOORLIE POLICY MET
DATA PERIOD: 05/01/2009 TO 12/01/2009
FOR DAILY TIME RANGES OF 0010 TO 2400
SAMPLING TIME: 10 MINUTES
DATA RECOVERY: 100.0%

Week 3



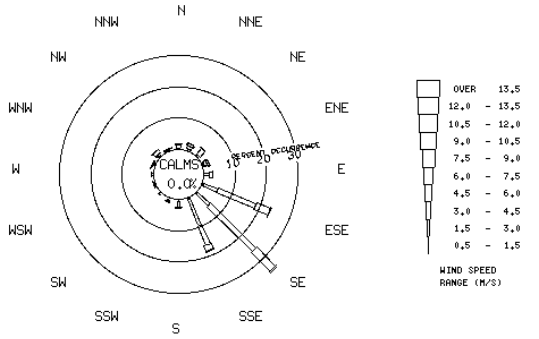
WIND ROSE FOR KALGOORLIE POLICY MET
DATA PERIOD: 12/01/2009 TO 19/01/2009
FOR DAILY TIME RANGES OF 0010 TO 2400
SAMPLING TIME: 10 MINUTES
DATA RECOVERY: 100.0%

Week4



WIND ROSE FOR KALGOORLIE POLICY MET
DATA PERIOD: 19/01/2009 TO 26/01/2009
FOR DAILY TIME RANGES OF 0010 TO 2400
SAMPLING TIME: 10 MINUTES
DATA RECOVERY: 100.0%

Week 5



WIND ROSE FOR KALGOORLIE POLICY MET
DATA PERIOD: 26/01/2009 TO 03/02/2009
FOR DAILY TIME RANGES OF 0010 TO 2400
SAMPLING TIME: 10 MINUTES
DATA RECOVERY: 100.0%

Week 6

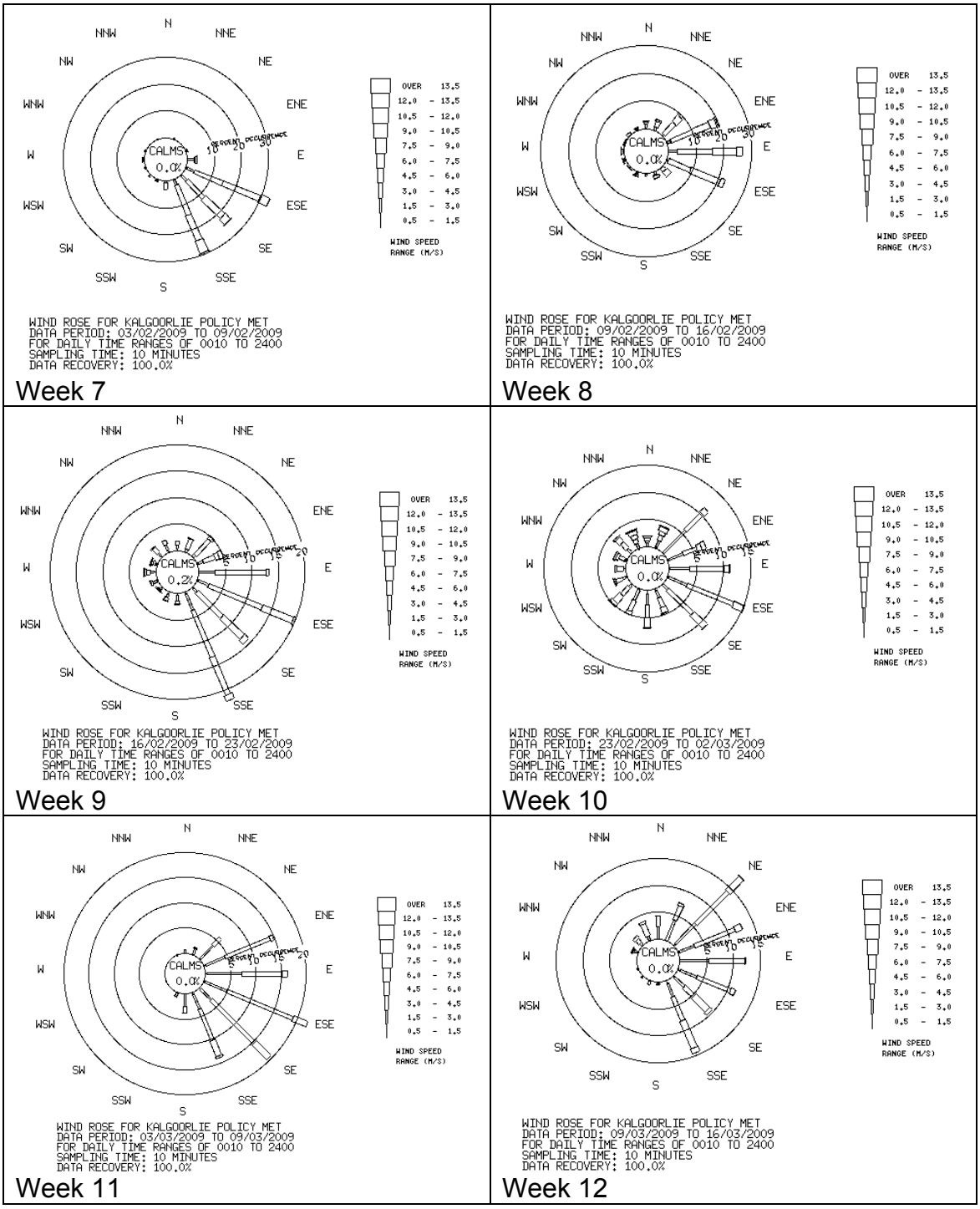


Figure 15 Windroses for each weekly period the Radiello samplers were collecting data (22/12/2008 – 16/03/2009)

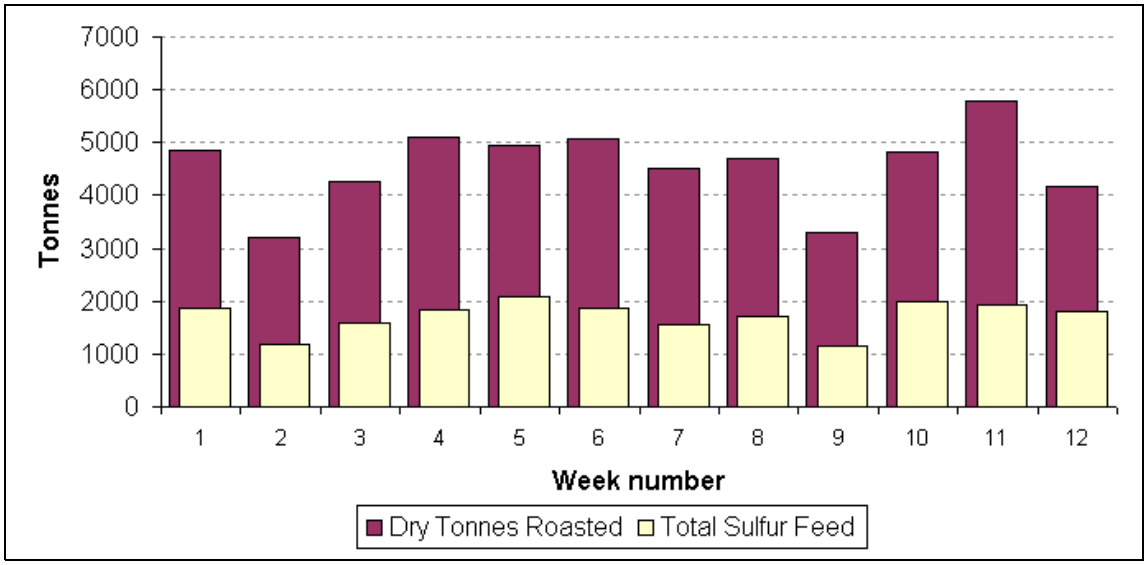


Figure 16 Tonnage throughput of the Gidji roaster for eack weekly period the Radiello samplers were collecting data (22/12/2008 – 16/03/2009)

5.0 CONCLUSIONS AND RECOMMENDATIONS

The 1992 and 2003 versions of the Environmental Protection (Goldfields Residential Areas) (Sulfur Dioxide) Policy have set a not-to-be-exceeded one-hour limit and a one-hour 'standard' (although no longer called this). The limit and standard have become progressively more stringent. From 2008 onward the limit has been 0.25 ppm (no exceedence allowed) and the "standard" has been 0.2 ppm (exceedence on one day per year allowed). Industries are required under a condition of licence to comply with the limit.

Ambient SO_2 concentrations measured during the period 1999–2008 have been compared to the standards and limits as they applied at various times under the 1992 and 2003 EPPs. The relevant EPP limit was exceeded only once during the study period, in 2005. This exceedence was measured at the Coolgardie Primary School station in 2005, and was found to have been caused by the Gidji Roaster. The number of allowed exceedences per year of the 'standard' was complied with in all years except for 2000.

The 2003 EPP 'standard' was designed to match the standard and goal for SO_2 in the National Environment Protection Council (Ambient Air Quality) Measure 2008 (NEPM). The NEPM also set a standard and exceedence allowance for two other averaging times, namely a daily average 0.08 ppm (exceedence on one day per year allowed) and an annual average of 0.02 ppm (no exceedences allowed). Ambient SO_2 concentrations measured during the period 1999–2008 have been compared to these NEPM standards to determine if the progressively reducing the EPP limit and 'standard' have also been effective in achieving the NEPM standards to the allowed exceedence levels by 2008. The results were as follows:

- Although the ambient air concentrations of SO_2 in the Goldfield EPP areas exceeded the NEPM one-hour standard on 18 occasions during 1999 to 2008, the Air NEPM goal of no more than one exceedence per year at any one

location was met in all years except 2000, during which there was three exceedences at one monitoring station. Noting that as the goal is for compliance by 2008, it has been achieved;

- The 24-hour SO_2 Air NEPM standard was not exceeded at any station within the EPP area at any time between 1999 and 2008.

- Annual average SO_2 concentrations were less than 10% of the NEPM ambient air quality standard of 0.02 ppm at all stations during the study period.

All stations showed no common seasonal trends in SO_2 concentrations, with maximum concentrations occurring during any season. Most stations displayed a trend of higher day-time concentrations than night-time concentrations (on average 1.6 times higher).

During exceedences of the one-hour SO_2 Air NEPM standard, winds were typically from the north or south, identifying either the Nickel Smelter or the Gidji Roaster and/or KBGM respectively as the probable source of SO_2.

Monitoring stations within the Goldfields EPP areas recorded the highest SO_2 concentrations in WA when compared to other monitoring sites. However concentrations were lower than those recorded at Port Pirie (SA) and Mt. Isa (QLD).

Results of the passive monitoring for SO_2 in the Kalgoorlie-Boulder area shows that the Goldfields Highway recorded the highest weekly average concentration of 0.087 ppm and the highest overall average of 0.035 ppm. The weekly sampling was done over about 3 months, and high concentrations observed suggest that further investigation is warranted. It would also be desirable to further validate the passive samples by co-locating them at sites with active samplers to get a direct comparison.

Analysis of SO_2 concentrations in the Goldfields EPP areas has shown minimal exceedences of the EPP limit and “standards” and achievement of the NEPM goal. However the continuous monitoring at the Satellite station and the limited Radiello sampling shows that SO_2 concentrations outside the EPP areas but close to SO_2 emission sources may at times be high and may adversely affect people in the area, such as motorists.

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http://www.dec.wa.gov.au/science-and-research/index.html

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http://www.npi.gov.au

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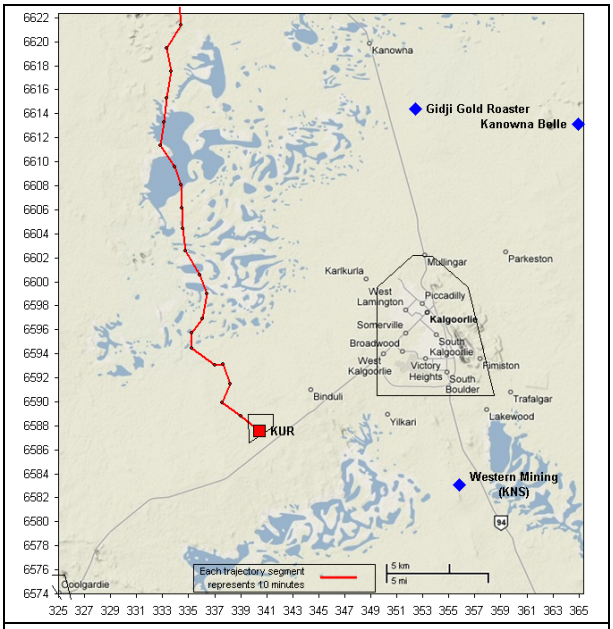
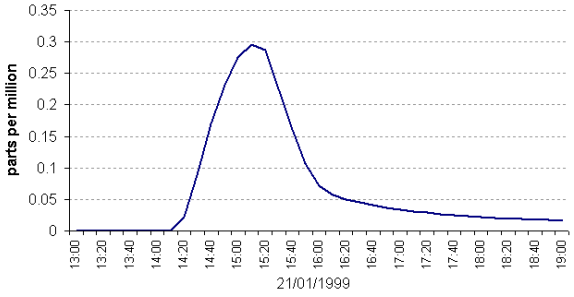
APPENDIX 1 Back-trajectories for exceedences of the Goldfields EPP SO_2 standard

21 January 1999 exceedence at KUR

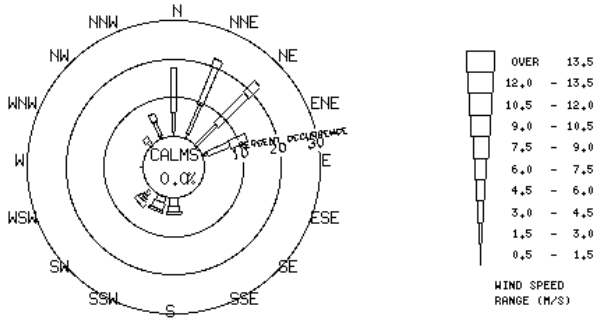


Back trajectory to KUR ending at 3:10 pm on 21/01/1999

One hour averaged concentration



Windrose



WIND ROSE FOR KALGOORLIE POLICY MET
DATA PERIOD: 21/01/1999 TO 21/01/1999
FOR DAILY TIME RANGES OF 0010 TO 2400
SAMPLING TIME: 10 MINUTES
DATA RECOVERY: 100.0%

Pollutant

SO_2

Monitoring site

Kurrawang (KUR)

Highest concentration

0.295 ppm

Averaging period

1 hour moving average

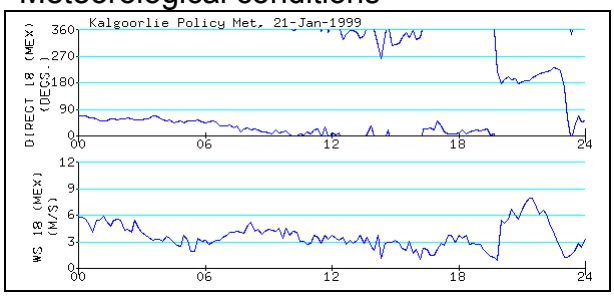
NEPM Standard

0.245 ppm

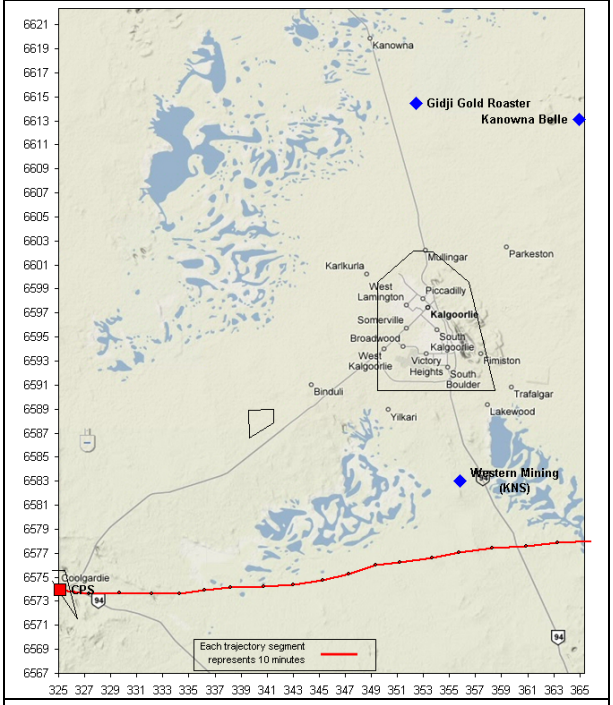
Description of event
21 January 1999 15:10 at KUR

The wind direction immediately prior to the exceedence was from an northerly direction, indicating the likely source of SO_2 to be the either the Gidji roaster or KBGM.

Meteorological conditions

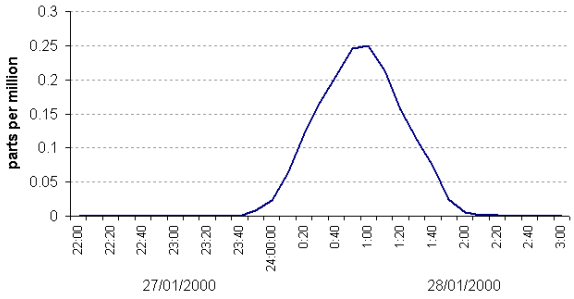


28 January 2000 exceedence at CPS

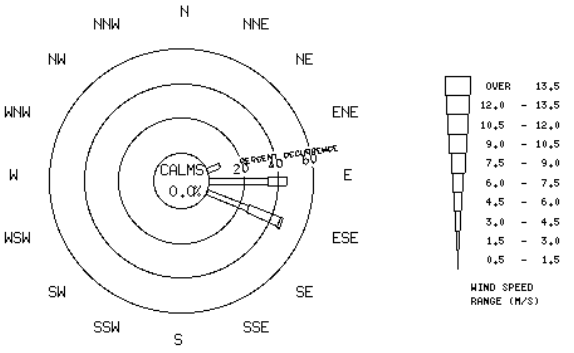


Back trajectory to CPS ending at 1:00 am on 28/01/2000

One hour averaged concentration



Windrose



WIND ROSE FOR KALGOORLIE POLICY MET
DATA PERIOD: 27/01/2000 TO 28/01/2000
FOR DAILY TIME RANGES OF 2200 TO 0300
SAMPLING TIME: 10 MINUTES
DATA RECOVERY: 100.0%

Pollutant

SO_2

Monitoring site

Coolgardie Primary School (CPS)

Highest concentration

0.250 ppm

Averaging period

1 hour moving average

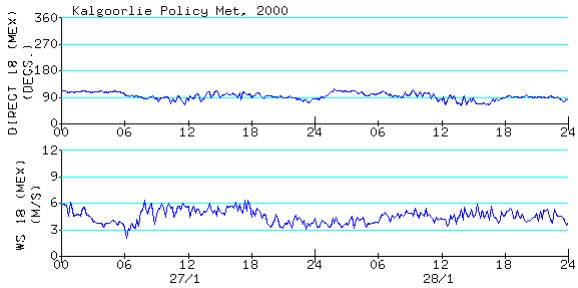
NEPM Standard

0.245 ppm

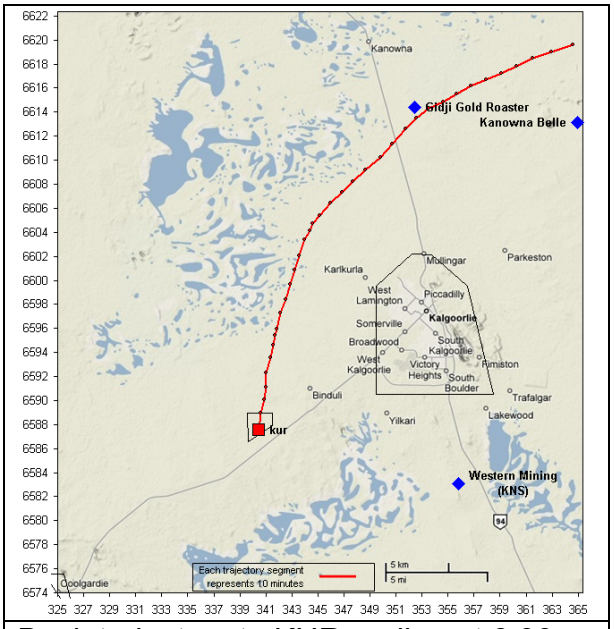
Description of event
28 January 2000 01:00 at CPS

The wind direction immediately prior to the exceedence was from an easterly direction, indicating the likely source of SO_2 to be the Kalgoorlie Nickel smelter.

Meteorological conditions

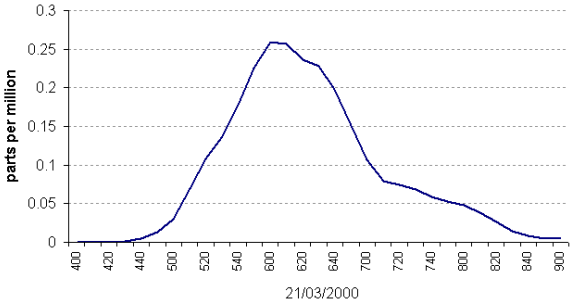


21 March 2000 exceedence at KUR

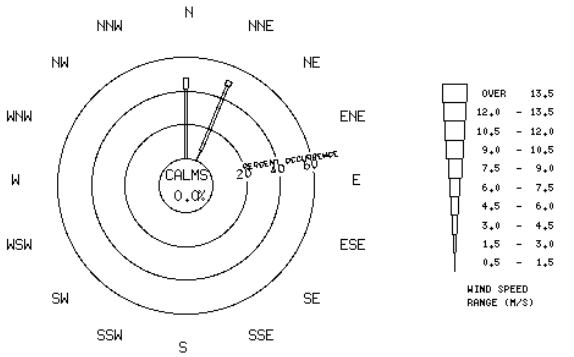


Back trajectory to KUR ending at 6:00 am on 21/03/2000

One hour averaged concentration



Windrose



WIND ROSE FOR KALGOORLIE POLICY MET
DATA PERIOD: 21/03/2000 TO 21/03/2000
FOR DAILY TIME RANGES OF 0400 TO 0900
SAMPLING TIME: 10 MINUTES
DATA RECOVERY: 100.0%

Pollutant

SO_2

Monitoring site

Kurrawang Aboriginal Community (KUR)

Highest concentration

0.259 ppm

Averaging period

1 hour moving average

EPP Standard

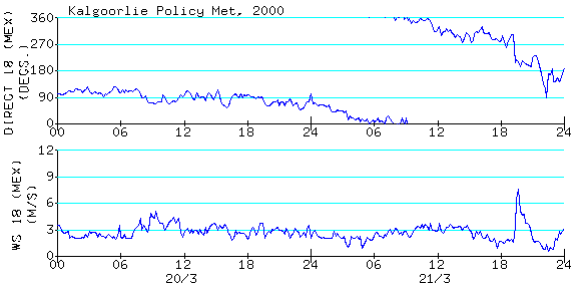
0.245 ppm

Description of event
21 March 2000 06:00 at KUR

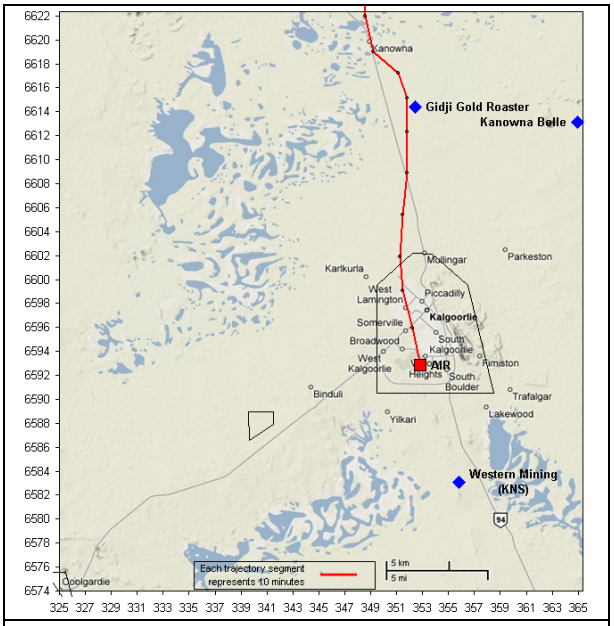
Wind conditions immediately prior to the exceedence were still. On the previous day however winds averaged 3 m/s from an easterly direction.

It is believed emissions gradually drifted from an easterly direction following the still conditions, indicating the Gidji Gold Roaster to be the likely source of SO_2.

Meteorological conditions

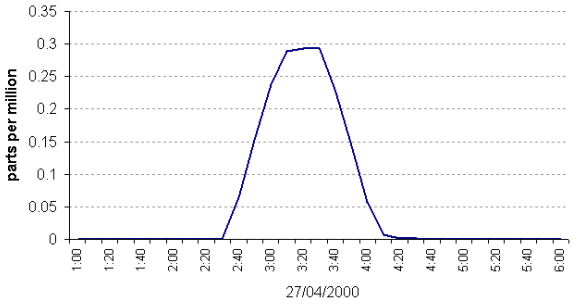


27 April 2000 exceedence at AIR

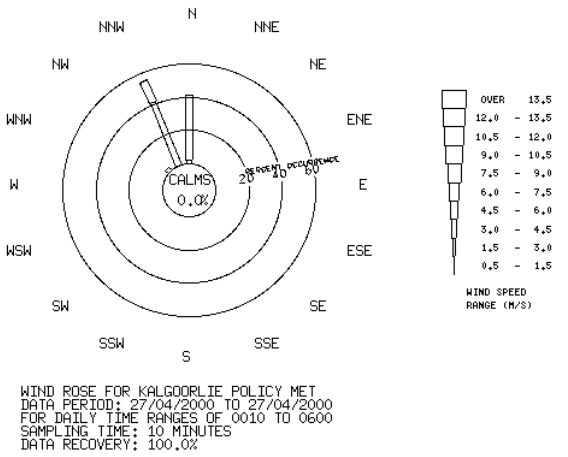


Back trajectory to AIR ending at 3:00 pm on 27/04/2000

One hour averaged concentration



Windrose



WIND ROSE FOR KALGOORLIE POLICY MET
DATA PERIOD: 27/04/2000 TO 27/04/2000
FOR DAILY TIME RANGES OF 0010 TO 0600
SAMPLING TIME: 10 MINUTES
DATA RECOVERY: 100.0%

Pollutant

SO_2

Monitoring site

Kalgoorlie Airport (AIR)

Highest concentration

0.294 ppm

Averaging period

1 hour moving average

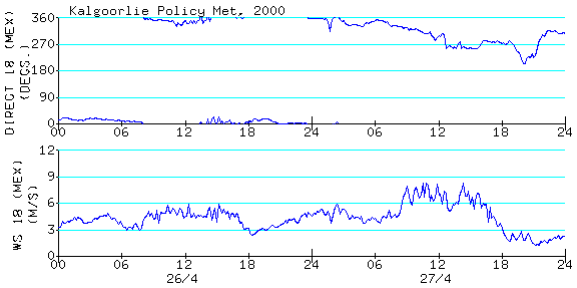
EPP Standard

0.245 ppm

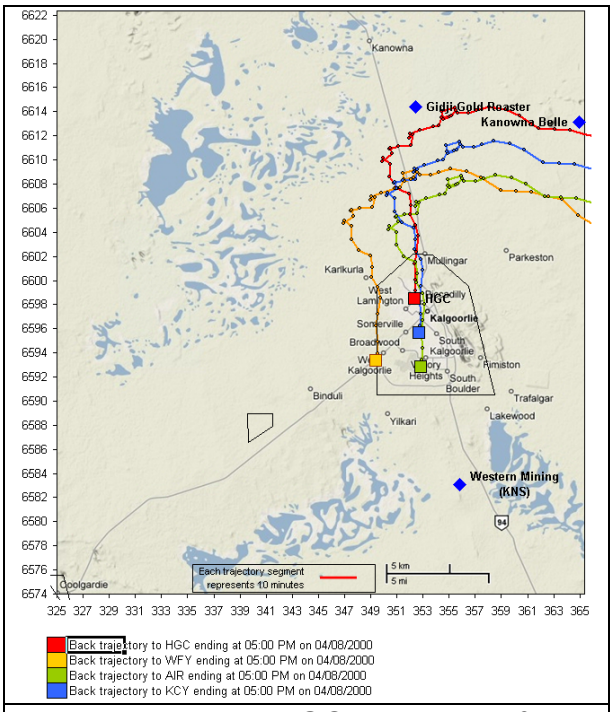
Description of event
27 April 2000 03:00 at AIR

Wind conditions on the day of the exceedence were predominantly northerly, indicating the potential source of SO_2 to be the Gidji Roaster, located approximately 16 km north of Kalgoorlie and this monitoring station.

Meteorological conditions

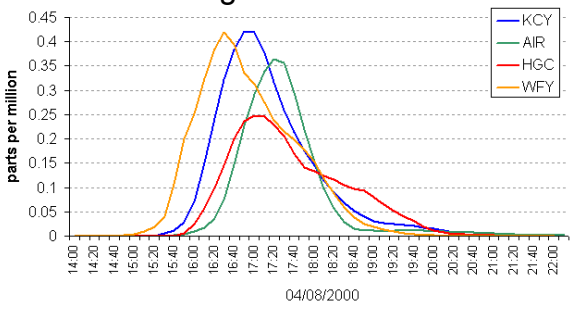


4 August 2000 exceedences at HGC, WFY, AIR & KCY

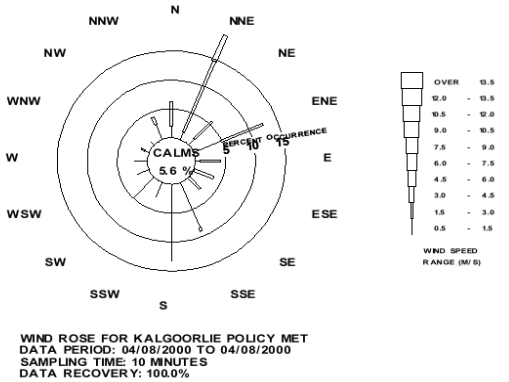


Back trajectory to HGC, WFY, AIR & KCY ending at 5:00 pm on 04/08/2000

One hour averaged concentration



Windrose



Pollutant

SO_2

Monitoring sites

Hannans Golf Course (HGC)
Westrail Freight Yard (WFY)
Kalgoorlie Airport (AIR)
Kalgoorlie Council Yard (KCY)

Highest concentrations

0.324 ppm	(HGC – 1610)
0.275 ppm	(HGC – 1710)
0.248 ppm	(WFY – 1700)
0.364 ppm	(AIR – 1720)
0.322 ppm	(KCY – 1630)
0.260 ppm	(KCY – 1730)

Averaging period

1 hour moving average

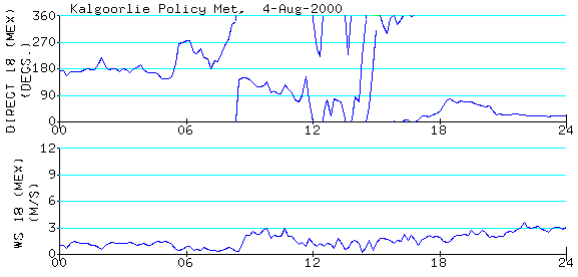
EPP Standard

0.245 ppm

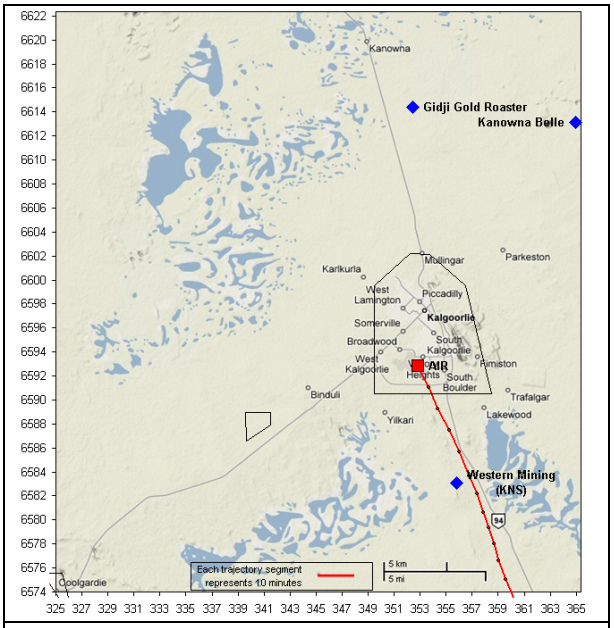
Description of event
4 August 2000 16:10 – 17:30 at HGC, WFY, AIR & KCY

A wind gust from a north, north easterly direction indicated the likely source to be the Gidji Roaster or Kanowna Bell Gold Mine, located approximately 16 km to the north of Kalgoorlie and the above mentioned monitoring stations.

Meteorological conditions

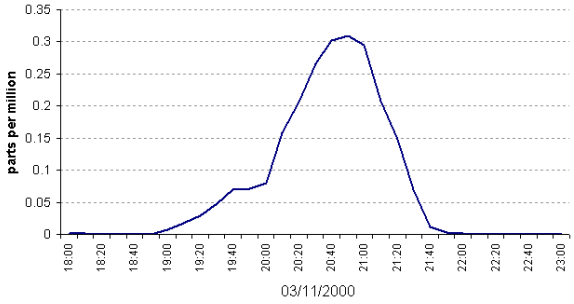


3 November 2000 exceedence at AIR

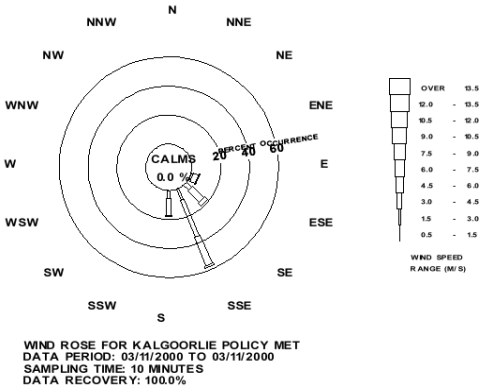


Back trajectory to AIR ending at 9:00 pm on 03/11/2000

One hour averaged concentration



Windrose



Pollutant

SO_2

Monitoring site

Kalgoorlie Airport (AIR)

Highest concentration

0.309 ppm

Averaging period

1 hour moving average

EPP Standard

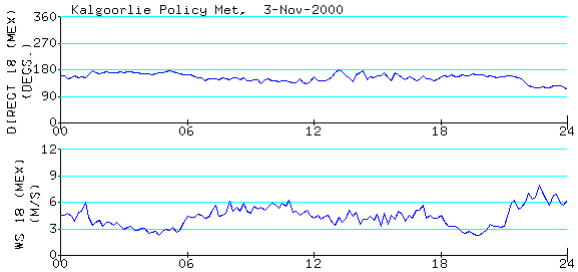
0.245 ppm

Description of event
3 November 2000 21:00 at AIR

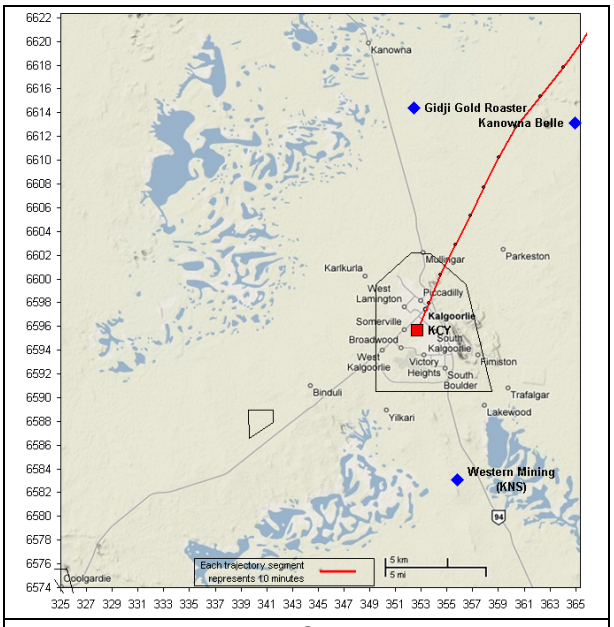
Wind direction during the exceedence event was south to south easterly indicating the potential SO_2 source to be the Kalgoorlie Nickel Smelter located 11 km southeast of the monitoring station.

Wind speed increased in the hour prior to the exceedence event to approximately 10-15 km/hr between 21:00-21:30, when the exceedence took place.

Meteorological conditions

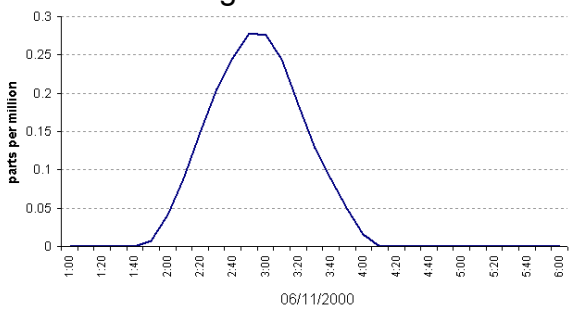


6 November 2000 exceedence at KCY

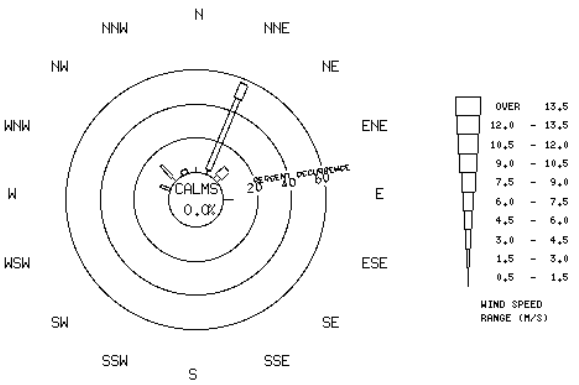


Back trajectory to KCY ending at 3:00 am on 06/11/2000

One hour averaged concentration



Windrose



WIND ROSE FOR KALGOORLIE POLICY MET
DATA PERIOD: 06/11/2000 TO 06/11/2000
FOR DAILY TIME RANGES OF 0100 TO 0600
SAMPLING TIME: 10 MINUTES
DATA RECOVERY: 100.0%

Pollutant

SO_2

Monitoring site

Kalgoorlie Council Yard (KCY)

Highest concentration

0.278 ppm

Averaging period

1 hour moving average

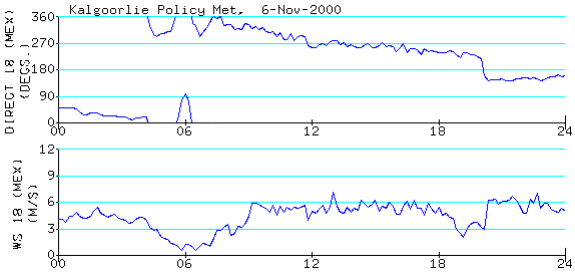
EPP Standard

0.245 ppm

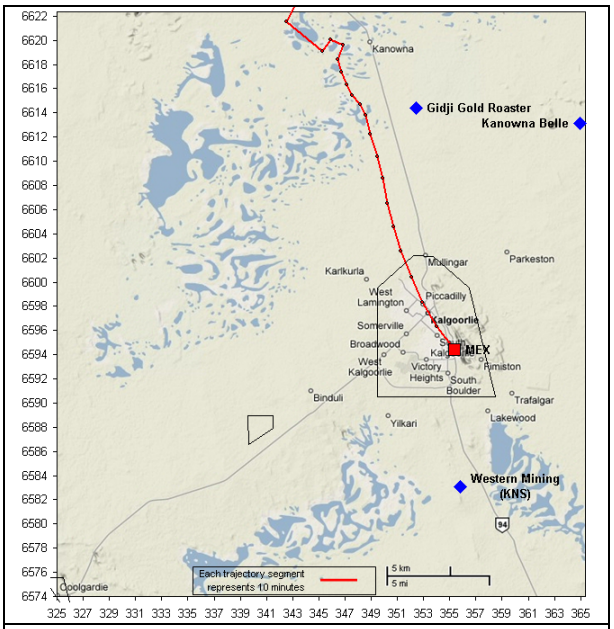
Description of event
6 November 2000 03:00 at KCY

Winds from a north easterly direction dominated during the exceedence event indicating the Gidji Roaster, 16 km north of Kalgoorlie, to be the most likely source of the high SO_2 concentration.

Meteorological conditions

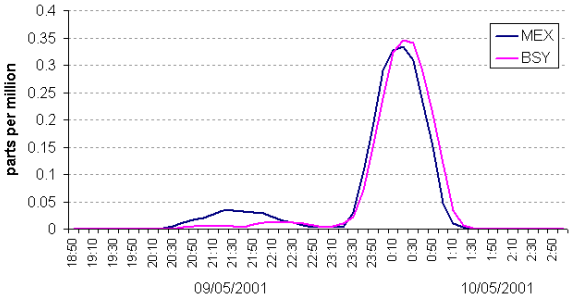


10 May 2001 exceedences at MEX & BSY

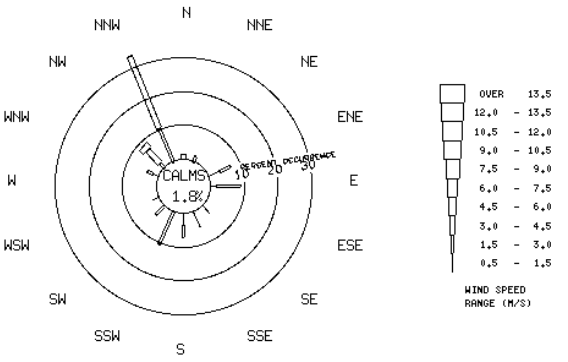


Back trajectory to MEX ending at 11:50 pm on 09/05/2001

One hour averaged concentration



Windrose



WIND ROSE FOR KALGOORLIE POLICY MET
DATA PERIOD: 09/05/2001 TO 10/05/2001
FOR DAILY TIME RANGES OF 2100 TO 0130
SAMPLING TIME: 10 MINUTES
DATA RECOVERY: 100.0%

Pollutant

SO_2

Monitoring site

Metals Exploration (MEX)
Boulder Shire Yard (BSY)

Highest concentration

0.334 ppm (MEX)
0.346 ppm (BSY)

Averaging period

1 hour moving average

EPP Standard

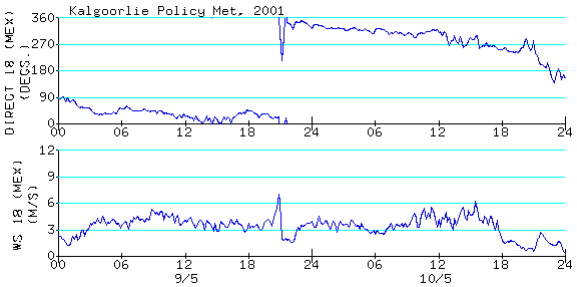
0.245 ppm

Description of event
10 May 2001 at MEX & BSY

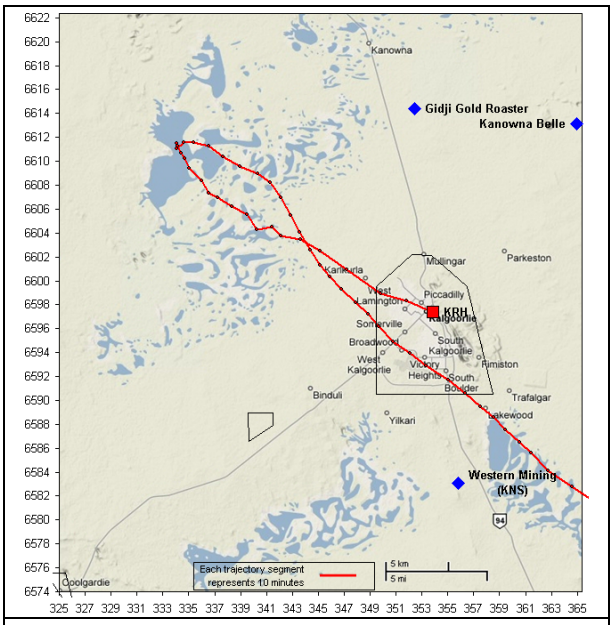
The wind direction shifted from north to northwest between 23:00 and 24:00 on the 9 May 2001 causing the exceedence event on the 10th.

The Gidji Roaster located 22 km north east of the MEX monitoring station and 24 km north east of the BSY station is the possible source of the high SO_2 concentration.

Meteorological conditions

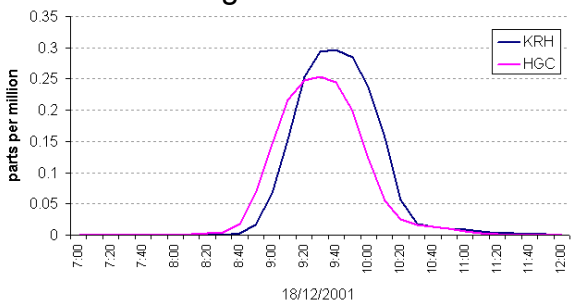


18 December 2001 exceedences at KRH & HGC

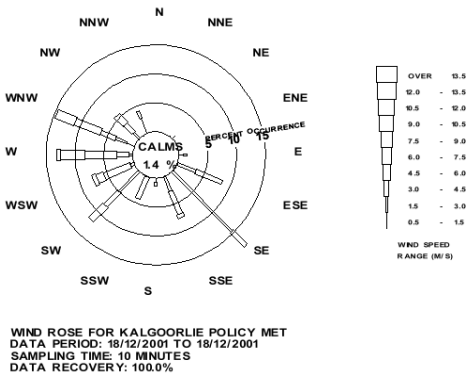


Back trajectory to KRH ending at 9:40 am on 18/12/2001

One hour averaged concentration



Windrose



Pollutant

SO_2

Monitoring site

Kalgoorlie Regional Hospital (KRH)
Hannans Golf Course (HGC)

Highest concentration

0.296 ppm (KRH)
0.254 ppm (HGC)

Averaging period

1 hour moving average

EPP Standard

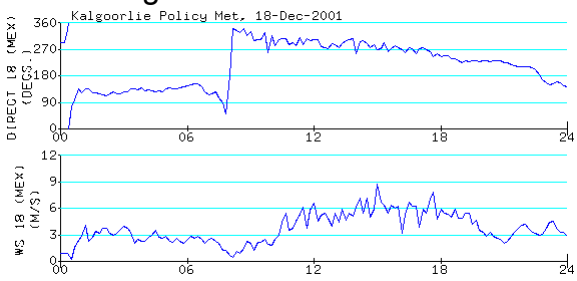
0.245 ppm

Description of event
18 December 2001 at KRH

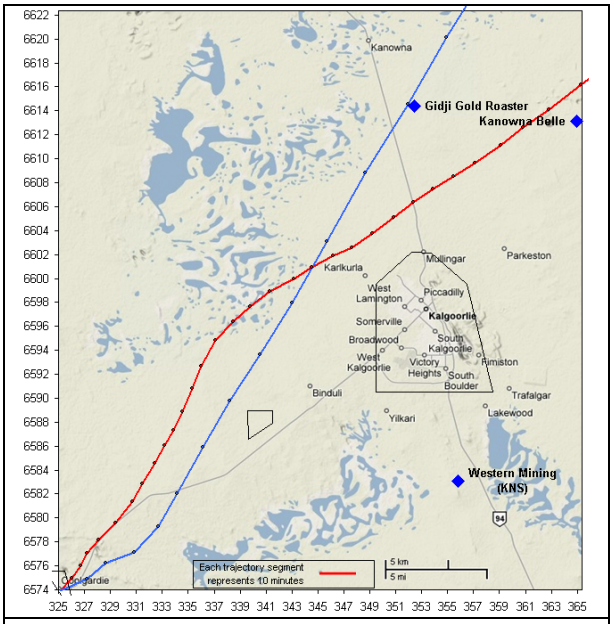
A wind gust of approximately 12 km/hr was recorded from a north westerly direction at the time of the SO_2 exceedence.
The direction of the wind indicates the Kalgoorlie Nickel Smelter located approximately 8 km south of Kalgoorlie to be the most probable source.

Wind speeds continued to increase following the exceedence up to 25 km/hr by 11:30, assisting SO_2 emissions to dissipate after the exceedence event.

Meteorological conditions

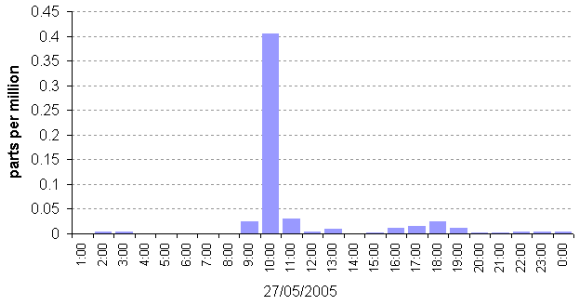


27 May 2005 exceedence at CPS

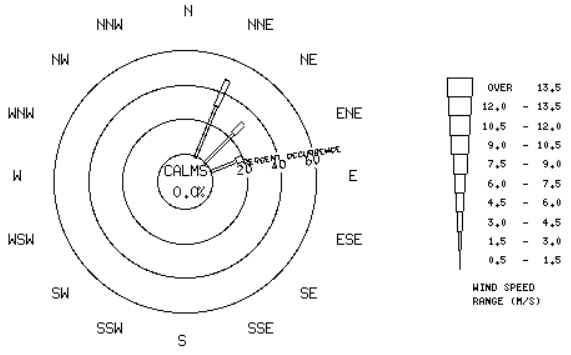


Back trajectory from CPS ending at 10 am on 27/05/2005 (Red track is data from MEX, Blue track is data from the KNS sodar @ 200m)

One hour averaged concentration



Windrose



WIND ROSE FOR KALGOORLIE POLICY MET
DATA PERIOD: 27/05/2005 TO 27/05/2005
FOR DAILY TIME RANGES OF 0800 TO 1200
SAMPLING TIME: 10 MINUTES
DATA RECOVERY: 100.0%

Pollutant

SO_2

Monitoring site

Coolgardie Primary School (CPS)

Highest concentration

0.40 ppm

Averaging period

1 clock hour

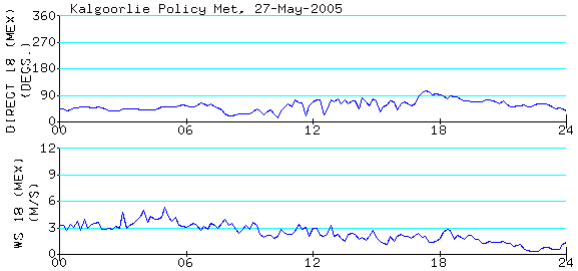
EPP Standard

0.20 ppm

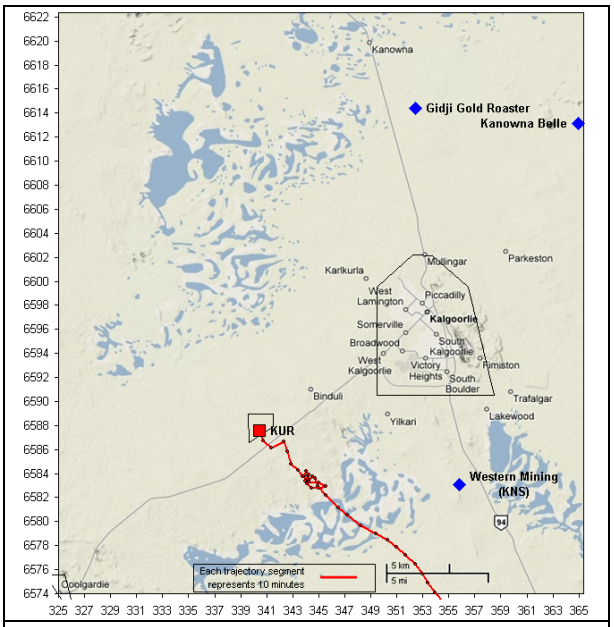
Description of event
27 May 2005 10:00 at CPS

The wind changed direction from north easterly to more northerly at approximately 3 m/s between 07:00 and 10:00 when the exceedence occurred. This indicates the location of the SO_2 source to be the Gidji Roaster 16 km north of Kalgoorlie. Kalgoorlie Consolidated Gold Mine was fined $25,000 for this licence breach in 2005.

Meteorological conditions

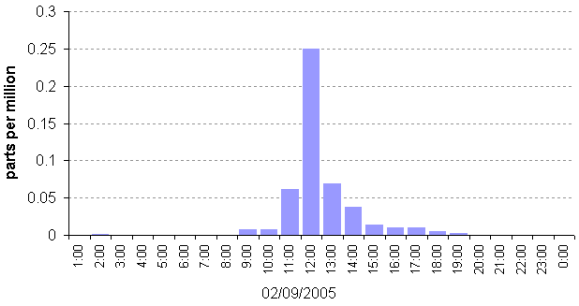


2 September 2005 exceedence at KUR

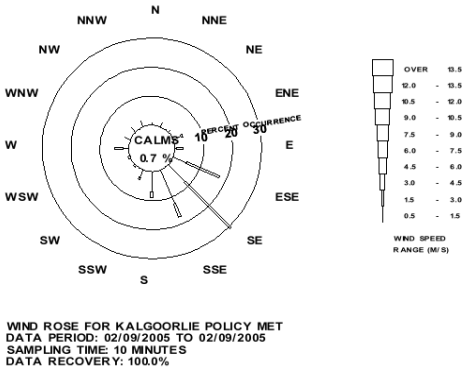


Back trajectory from KUR ending at 12 noon on 02/09/2005

One hour averaged concentration



Windrose



Pollutant

SO_2

Monitoring site

Kurrawang Aboriginal Community (KUR)

Highest concentration

0.25 ppm

Averaging period

1 clock hour

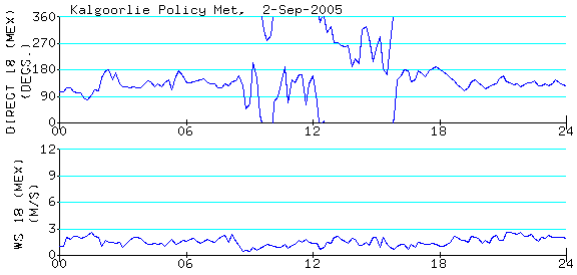
EPP Standard

0.20 ppm

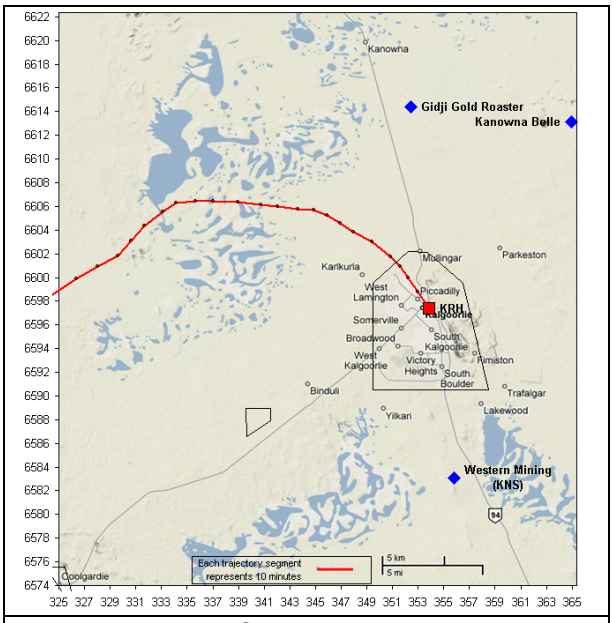
Description of event
2 September 2005 12:00 at KUR

The wind direction at the time of the exceedence was south easterly, and moving at a speed of 1 to 2 m/s. This indicates the likely source of SO_2 to be the Kalgoorlie Nickel Smelter located approximately 8 km south of Kalgoorlie and 16 km southeast of the Kurrawang monitoring station.

Meteorological conditions

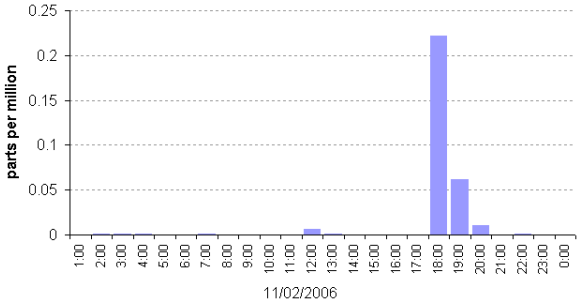


11 February 2006 exceedences at KRH & KCY

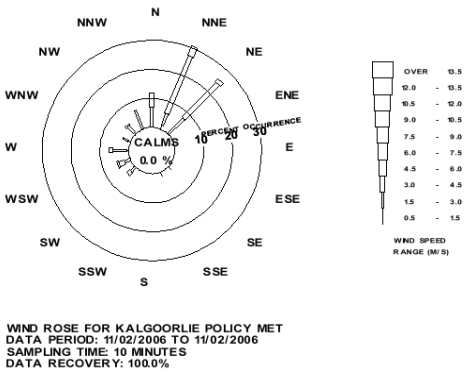


Back trajectory from KRH ending at 6 pm on 11/02/2006

One hour averaged concentration



Windrose



Pollutant

SO_2

Monitoring site

Kalgoorlie Regional Hospital (KRH)
Kalgoorlie Council Yard (KCY)

Highest concentration

0.222 ppm (KRH)
0.220 ppm (KCY)

Averaging period

1 clock hour

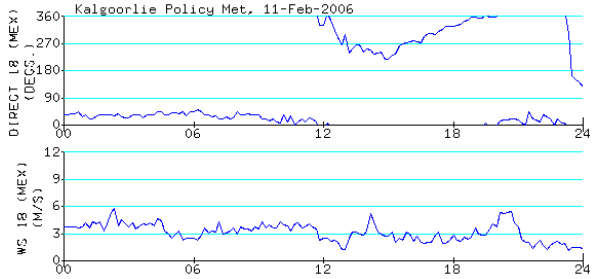
EPP Standard

0.20 ppm

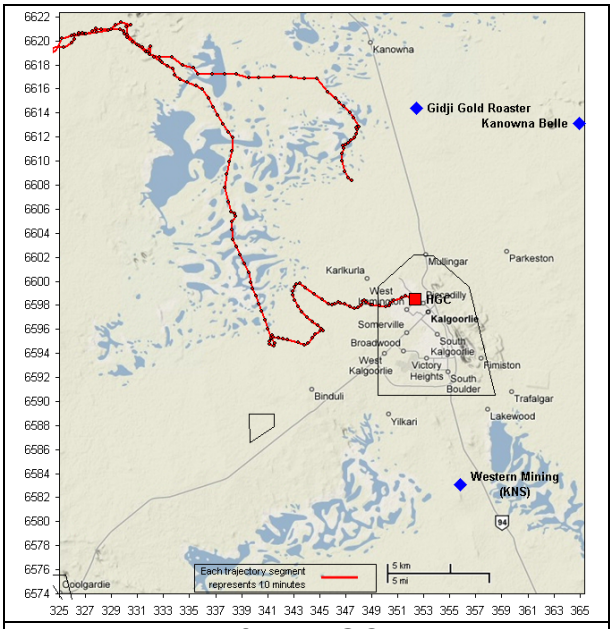
Description of event
11 February 2006 18:00 at KRH & KCY

Wind direction was predominantly north westerly at 18:00 during the exceedence, with moderate winds of approximately 10–15 km/hr recorded. The location of the SO_2 source is indeterminate.

Meteorological conditions

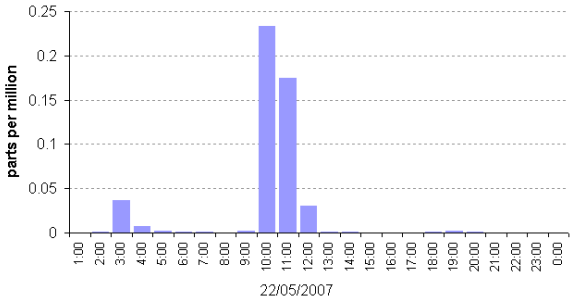


22 May 2007 exceedence at HGC

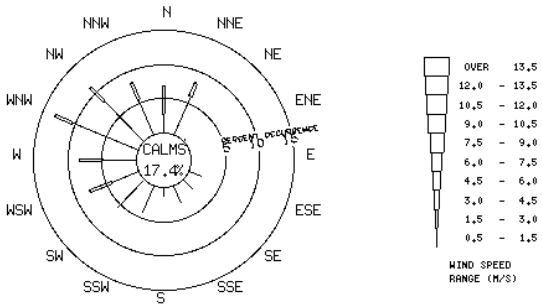


Back trajectory from HGC ending at 10 am on 22/05/2007

One hour averaged concentration



Windrose



WIND ROSE FOR KALGOORLIE POLICY MET
DATA PERIOD: 22/05/2007 TO 22/05/2007
FOR DAILY TIME RANGES OF 0010 TO 2400
SAMPLING TIME: 10 MINUTES
DATA RECOVERY: 100.0%

Pollutant

SO_2

Monitoring site

Hannans Golf Course (HGC)

Highest concentration

0.233 ppm

Averaging period

1 clock hour

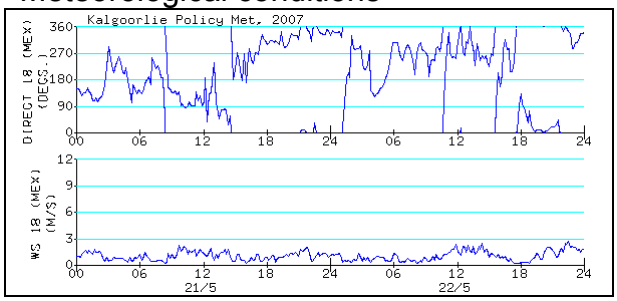
EPP Standard

0.20 ppm

Description of event
22 May 2007 10:00 at HGC

Wind direction was predominantly north westerly at 10:00 during the exceedence, with low winds of approximately 1–2 m/s recorded. The location of the SO_2 source is most likely either the Gidji roaster or KBGM.

Meteorological conditions

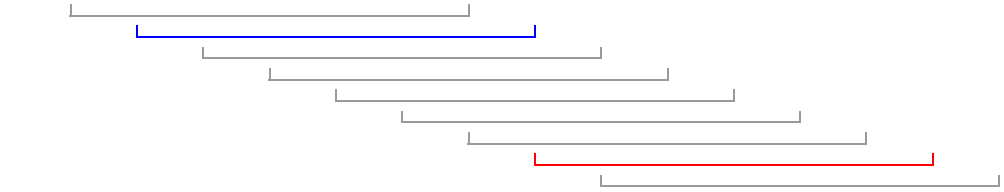


Appendix 2 Moving Averages and Clock Hours

In the 1992 Goldfields EPP, the method used to calculate exceedences was the method of moving averages. This method ran a one hour time window across the data in stepwise increments based on the smallest data time interval. Averages were calculated from the relevant number of data points up to and including the end time of the data.

For example, on the 4th August 2000, there was an exceedence of the EPP at the Kalgoorlie Council Yard monitoring site. The table below shows the concentrations on the day for every 10 minute period from 1530 hours (3:30 pm) to 1740 hours (5:40 pm). Each datum is the average SO_2 concentration for the 10 minute period ending at the indicated time stamp.

TIME	1530	1540	1550	1600	1610	1620	1630	1640	1650	1700	1710	1720	1730	1740
PPM	0.027	0.038	0.1	0.261	0.477	0.55	0.503	0.414	0.32	0.255	0.22	0.187	0.163	0.132



Moving Average			0.242	**0.322**	0.384	0.421	0.420	0.377	0.317	**0.260**	0.213
Time			1620	1630	1640	1650	1700	1710	1720	1730	1740

Within this period, there are two separate exceedences of the one hour Goldfields EPP standard of 0.245 ppm, one ending at 1630 hours (marked in blue) and again at 1730 hours (marked in red). To qualify as exceedences, these (or any) two hourly averages must be calculated using separate and independent data points, hence their separation by at least one hour.

The maximum concentration for that day is 0.421 ppm occurring at 1650 hours.

The 2003 Goldfields EPP changed the method of calculating averages to clock hours. This brought the EPP into line with the method used by the National Environment Protection Measure (NEPM) to calculate averages. Using this method on the above data where one is constrained to average from one clock hour to the next, there is only one hour that exceeds the standard. This occurs at 1700 hours (the end time of the one hour period) with a concentration of 0.420 ppm. The number of exceedences allowed under the 2003 Goldfields EPP is now expressed as exceedence days, so regardless of the number of clock hours exceeded during one day at a particular site, it is counted as only one exceedence. This parallels the method used in the current Air NEPM.