Appendix 6

Air quality assessment

Pacific Environment Limited

Consulting • Technologies • Monitoring • Toxicology

PROJECT TITLE: ERA Ranger 3 Deeps Air Quality Assessment

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PREPARED FOR: Energy Resources of Australia Ltd

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GLOSSARY OF TERMS

Term	Description
Air NEPM	National Environment Protection Measure for Ambient Air Quality
BoM	Bureau of Meteorology
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CRPM	Chemically reactive plume model
EIS	Environmental Impact Statement
EPBC Act	Environmental Protection and Biodiversity Conservation Act 1999
ERA	Energy Resources of Australia Ltd
HME	Heavy Mining Equipment
NO_2	Nitrogen dioxide
NT EPA	Northern Territory Environment Protection Authority
OLM	Ozone limited method
PM	Particulate matter
PM_{10}	Particulate matter with an aerodynamic diameter less than 10 µm
$PM_{2.5}$	Particulate matter with an aerodynamic diameter less than 2.5 µm
RPA	Ranger Project Area
SO_2	Sulfur dioxide
TAPM	The Air Pollution Model
TSP	Total suspended particulate matter

1 INTRODUCTION

1.1 PROJECT DESCRIPTION

Energy Resources of Australia Ltd (ERA) proposes to develop and operate an underground mine and associated facilities at the existing Ranger uranium mine in the Alligator Rivers Region of the Northern Territory. The Ranger 3 Deeps underground mine (the Project) is situated within the footprint of the current Ranger uranium mine, on the Ranger Project Area (RPA), located 260 km east of Darwin and 11 km east of the regional centre of Jabiru.

ERA is required to undertake an Environmental Impact Assessment for the Project in accordance with the *Environmental Protection and Biodiversity Conservation Act 1999* (EPBC Act) and the *Northern Territory Environment Assessment Act*. In preparing the draft Environmental Impact Statement (EIS), ERA is required to assess the impact of Project emissions sources on ambient air quality.

Primary surface infrastructure will consist of a number of ventilation shafts. Ancillary infrastructure will include additional power generation, crushing plant and a backfill plant.

1.2 SCOPE OF WORK

The scope of work for the air quality assessment is based on the *Draft Guidelines for preparation of the EIS* issued by the Northern Territory Environment Protection Authority (NT EPA) and ERA’s *61801 ERA Ranger 3 Deeps – Air Quality Assessment – Ranger 3 Deeps Environmental Impact Assessment*, dated 11/07/2013.

The scope of work for the study was as follows:

- Estimate emissions from the underground mine.
- Model the meteorology of the project site and surrounds, using a representative meteorological year.
- Conduct a screening assessment to determine the effects of altering the location, exhaust temperature, height, and exit velocity of a single ventilation stack on ground-level concentrations.
- Conduct modelling to assess the existing, incremental (the Project) and cumulative impacts (existing with the Project).

2 SCREENING ASSESSMENT

The air quality assessment incorporated a sensitivity analysis to identify the relationship between stack configuration, release parameters, and resultant ground level concentrations (Pacific Environment, 2013). The outcomes of the screening assessment assisted in ensuring that subsequent modelling was sufficiently representative of the stack design. This analysis consisted of investigating the effects of varying exit velocity, temperature and stack height.

Specifically, the following parameters were compared and contrasted:

- Stack height was varied between 10 m and 5 m.
- Exhaust temperature was varied between 23ºC, 28ºC and 33ºC.
- Exit velocity was varied between 12.5 m/s, 18.7 m/s and 21 m/s.

Of the modelling parameters assessed, exit velocity was predicted to result in the greatest change to ground level concentrations at defined receptor locations. Therefore, the design velocity of 18.7 m/s was adopted for subsequent modelling. Conversely, the model output was relatively insensitive to exhaust temperature and so a mid-range value of 28˚C, representing ‘neutral’ buoyancy, was selected for subsequent modelling. While limited in extent, the modelling predicted that a 10 m stack height improved dispersion characteristics. Consequently, a 10 m stack height design was adopted as a modelling input.

3 ASSESSMENT CRITERIA

3.1 SUBSTANCES OF INTEREST

The assessment considered emissions associated with material movement, fuel combustion and ore processing for the Project and the existing Ranger mine. Based on operations where similar activities are undertaken, predominant substances that are typically derived from these activities were identified and evaluated. The evaluation considered the following aspects:

- whether the substance is emitted from Project and Ranger mine activities, and if so, the quantity of substance emitted
- the existing environmental values of the area surrounding the Ranger mine
- availability of relevant guidelines for the substance.

3.1.1 Particulate Matter

3.1.1.1 Suspended Particulate Matter

Suspended solids or liquids in air are referred to as Particulate Matter (PM). Concentrations of particles suspended in air can be classified by aerodynamic diameter, which describes the behaviour of the particle in the air based on its size and shape:

- Total Suspended Particulate (TSP) refers to the total amount of the PM suspended in air (regardless of size). Particles in air are subject to gravitational settling; particles larger than about 30 µm in aerodynamic diameter are likely to be removed by gravitational settling within a short time of being emitted (i.e. they settle to the ground or other surfaces within minutes). These larger particles are primarily associated with amenity or visibility issues. In addition, TSP has been modelled as a component of the Project radiation assessment.
- PM_{10} refers to the total of suspended particulate matter less than 10 µm in aerodynamic diameter. Particles in this size range can enter bronchial and pulmonary regions of the respiratory tract and can impact human health. Particles in this size range can remain suspended for up to a few days in the atmosphere.
- $PM_{2.5}$ refers to the total of suspended particulate matter less than 2.5 µm in aerodynamic diameter. Epidemiological studies have shown that particles in this size range are associated with greater health impacts on humans than other particle sizes. These particles can remain suspended for up to months at a time.

In addition to the suspended PM, deposited PM can cause environmental impact to amenity (e.g., dust on laundry, cars and other surfaces). This is commonly referred to as dust deposition (see Section 3.1.1.2).

Mining activities (ore processing, wheel generated dust from unpaved roads) are known to have significant PM emissions. Particulate matter emissions were therefore quantified and included in the dispersion modelling for this project.

3.1.1.2 Dust Deposition

Deposition is the process by which particles settle by the action of gravity and collect or deposit on surfaces. Deposition rate is defined as the mass of deposited material over a specified area and time period.

The deposition of dust is normally not a human health concern, but can be an amenity or nuisance related issue. The dust can settle on material objects, such as cars and laundry, which can lead to annoyance among people whose property is affected.

Radionuclides in deposited dust can increase soil radionuclide concentration and therefore are a potential risk to the environment. This data was used in the radiation assessment.

The deposition rate of particles is a function of the particles' settling velocities and atmospheric concentrations. Settling velocity depends on the particle size, particle density and properties of the atmosphere including density and viscosity. Particle sizes greater than 30 µm in aerodynamic diameter are primarily associated with dust deposition issues, as they settle rapidly near the source.

The activities that typically lead to dust deposition include earthmoving and mobile equipment activities on unpaved roads or exposed areas, preparation of sites for construction activities, and typical material movement activities. These activities are significant in mining operations and therefore dust deposition is included in the dispersion modelling.

3.1.2 Metals and Metalloids

Metals and metalloids can be toxic to humans when ingested and inhaled. Some metals and metalloids can imitate the action of an essential element in the body, interfering with the metabolic process to cause illness. These compounds can also accumulate in the body and in the food chain.

Uranium and its decay series elements have been assessed as part of the radiation assessment using other modelled parameters, i.e. radon and TSP. Based on previous analysis undertaken by ERA on the particulate constituents within TSP generated by Ranger operations, there are no other known metals or metalloids of concern within the Ranger mine, i.e., there are no metals/metalloids that have significant concentrations within the mine that are potentially toxic to humans.

Accordingly, metal emissions from the mine have not been considered relevant, and have not been quantified or included in the dispersion modelling.

3.1.3 Combustion Emissions

The combustion of fuels can form emissions that have the potential to adversely affect human health.

3.1.3.1 Sulfur Dioxide (SO_2)

Sulfur dioxide is the key member of a family of oxides of sulfur (SO_x). These gases form from the oxidation of sulfur when sulfur-containing fuels – such as coal and oil – are burnt.

The major health concerns associated with exposure to high concentrations of SO_2 include effects on breathing, respiratory illness, alterations in pulmonary defences and aggravation of existing cardiovascular disease. SO_2 is also a major precursor to acid rain, which is associated with the acidification of lakes and streams, accelerated corrosion of buildings and monuments, and reduced visibility.

Sulfur dioxide emissions associated with the Project and existing Ranger mine are from the combustion of fuels in vehicles and for power generation. SO_2 emissions have been quantified and considered in the dispersion modelling for this project.

3.1.3.2 Nitrogen Dioxide (NO_2)

Oxides of nitrogen (NO_x) comprises both nitrogen oxide (NO) and nitrogen dioxide (NO_2) emissions. NO_x exists in the atmosphere in a complex equilibrium between NO and NO_2 that is dependent on many atmospheric variables. The ambient guidelines only address the NO_2 fraction of NO_x, as it is the substance that has the potential to adversely affect human health and ecological parameters.

NO_x emissions associated with the Project and existing Ranger mine are from the combustion of fuels in vehicles and for power generation. NO_x emissions have been quantified and considered in the dispersion modelling for this project.

3.1.3.3 Carbon Monoxide (CO)

Carbon monoxide is produced from incomplete combustion of carbon-based materials, in conditions where carbon is only partially oxidised instead of being fully oxidised to form carbon dioxide (CO_2). Carbon monoxide is harmful to humans at high concentrations because its affinity for haemoglobin is more than 200 times greater than that of oxygen. When it is inhaled it is taken up by the blood and therefore reduces the capacity of the blood to transport oxygen. Health impacts occur at exposures significantly higher than typical ambient concentrations. These conditions are usually only met in areas close to heavy congested traffic when there is limited atmospheric dispersion. The proposed Project has a substantive ventilation system with relatively high flow designed to meet and exceed requirements for diesel particulate matter and radon. Through this design, CO concentrations will be reduced to a level that will not result in any health impact.

Therefore, it has not been considered in the dispersion modelling for this Project.

3.1.4 Odour

Odour is a sensation that can be caused by a great variety of compounds, known as odorants. At sufficiently high concentrations, they trigger odour responses in individuals who are exposed to them.

There are no significant odour or hydrogen sulphide emissions associated with the Ranger uranium mine or the Project. Consequently, odour and hydrogen sulphide were not quantified or considered in the dispersion modelling for this project.

3.1.5 Radon

Radon is a radioactive gas that is a decay product of uranium. Since radon emissions will be produced from mineralised rock faces, the incremental emissions of radon from the Project have been quantified and included in the dispersion modelling for the Project. Existing concentrations and cumulative impacts of radon are discussed separately in the EIS, using monitoring data which is deemed superior to predictive modelling of existing operations.

3.2 SELECTED SUBSTANCES

Based on the selection process described in Section 3.1, the following substances were quantified and included in the dispersion modelling:

- particulate matter with an aerodynamic diameter less than 10 µm (PM_{10})
- particulate matter with an aerodynamic diameter less than 2.5 µm ($PM_{2.5}$)
- dust deposition
- total suspended particles (TSP)[1]
- sulfur dioxide (SO_2)
- nitrogen dioxide (NO_2)
- radon (incremental only).

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[1] TSP has been modelled for both impacts to visual amenity and for the purposes of conducting a comprehensive radiation assessment. The results are presented in this report but are discussed separately in the EIS.

3.3 RELEVANT IMPACT CRITERIA

As no Northern Territory-specific air quality guidelines are in place, the guidelines within the National Environment Protection Measure for Ambient Air Quality (Air NEPM) are used to assess the impacts of the Project on residential receptors. The Air NEPM standards relevant to the study are presented in Table 1, and are relevant to public health impacts. Accordingly, applying human health criteria to receptor locations that are either ecological or cultural heritage sites is not of relevance to the assessment of ambient air quality.

The dust deposition guideline used for the assessment is provided in Table 2, and relates to amenity impacts. This criterion is applicable to ecological and cultural heritage locations.

Table 1 – Air NEPM Standards

Substance	Averaging Period	Maximum Ambient Concentration ppm	Maximum Ambient Concentration µg/m³	Allowable Exceedances
Nitrogen dioxide (NO_2)	1 hour	0.12	250	1 day a year
	1 year	0.03	62	none
Sulfur dioxide (SO_2)	1 hour	0.20	570	1 day a year
	1 day	0.08	230	1 day a year
	1 year	0.02	57	none
Particles as PM_{10}	1 day	-	50	5 days a year
Particles as $PM_{2.5}$	1 day	-	25	n/a
	1 year	-	8	n/a

Table 2 – Other Relevant Air Quality Standards

Substance	Averaging Period	Maximum Deposition Rate	Source
Deposited dust	1 year	4 g/m²/month	(NSW DEC, 2005)
TSP	1 year	90 µg/m³	

3.4 RECEPTORS

Dispersion models calculate ground level concentrations of selected pollutants at specific locations known as receptors, which are defined by coordinate points. Eleven specific points, known as discrete receptors, were selected around Ranger to represent a mixture of public (residential/commercial), culturally significant and ecologically significant locations. The coordinates of each discrete receptor are presented in Table 3, and Figure 1 shows the location of each in relation to the existing Ranger mine.[2] In addition to these discrete receptors, the model computed ground-level concentrations over a grid of receptors spaced 150 m apart, and extending 18 km by 18 km, with the existing Ranger mine near the centre of the grid. These gridded receptor points are used to create contour plots of the predicted ground-level concentrations.

Table 3 - Receptor Coordinates

Receptor ID		X-coordinate (km)	Y-coordinate (km)
1	Mudginberri	268.971	8606.000
2	009 Camp	271.054	8602.873
3	Jabiru	265.172	8597.924
4	Jabiru Airport (and businesses)	271.173	8599.572
5	Ranger mine village (contractor camp)	271.282	8598.574
6	Mount Brockman	273.558	8592.145
7	Tree Snake Dreaming	Coordinates removed at request of Mirarr	
8	R34 Cultural Heritage Site	274.640	8597.904
9	Retention Pond 1	272.308	8598.561
10	Magela Creek	274.353	8598.328
11	Georgetown Billabong	275.440	8597.369

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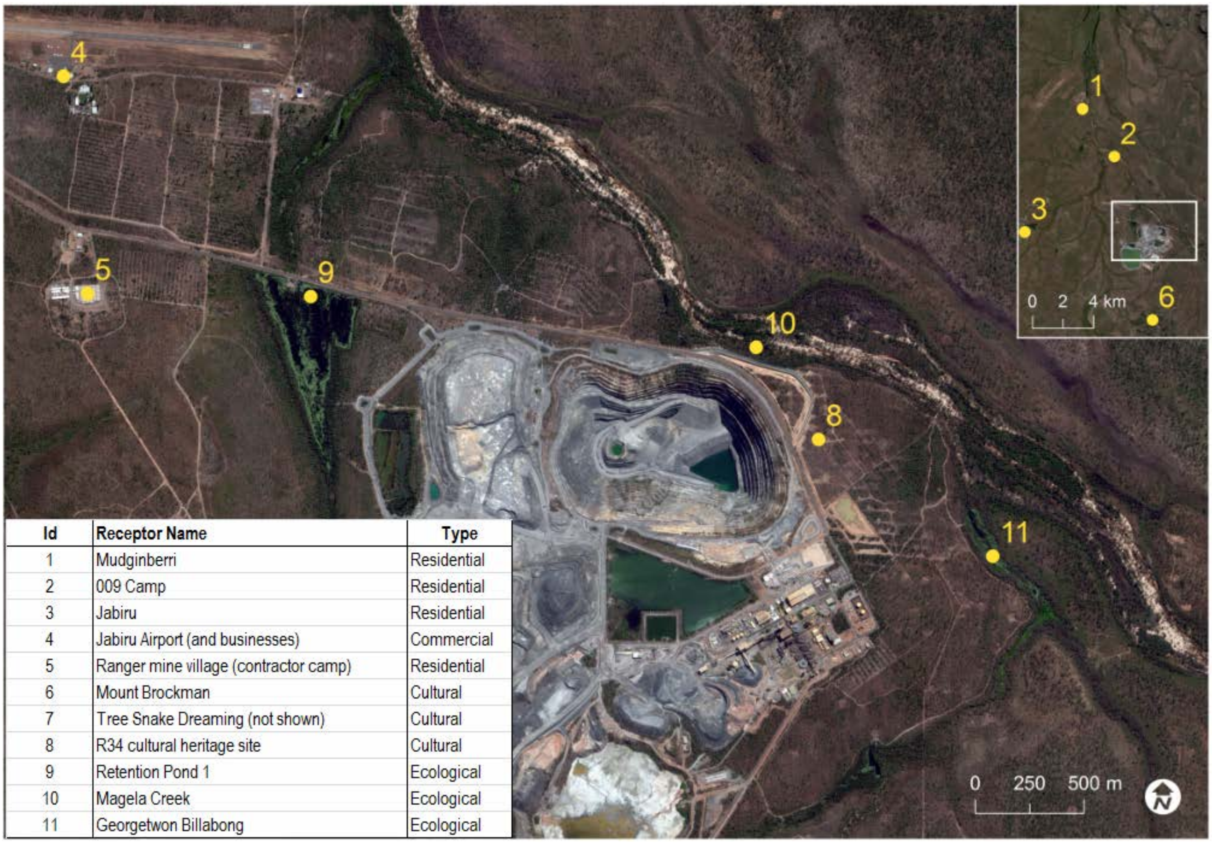
[2] The Tree Snake Dreaming site has been considered in this assessment however at the request of the Traditional Owners, is not disclosed in table 3 or figure 1.



Id	Receptor Name	Type
1	Mudginberri	Residential
2	009 Camp	Residential
3	Jabiru	Residential
4	Jabiru Airport (and businesses)	Commercial
5	Ranger mine village (contractor camp)	Residential
6	Mount Brockman	Cultural
7	Tree Snake Dreaming (not shown)	Cultural
8	R34 cultural heritage site	Cultural
9	Retention Pond 1	Ecological
10	Magela Creek	Ecological
11	Georgetown Billabong	Ecological

Figure 1 - Receptor Locations

3.5 EXISTING AIR ENVIRONMENT

Measured data for the existing air environment (background air quality) is unavailable for the Ranger mine, with the exception of radon. To assess the cumulative impact of the Project, the dispersion of emissions from existing emission sources was modelled to provide an estimate of the existing air quality at the site.

While this method assumes that there are no external sources of emissions such as windblown dust, it is assumed that in the area of interest for this study, existing concentrations are attributable to Ranger mine activities. The conservative nature of the emission estimation methods for both existing and Project sources is expansive enough to accommodate other extraneous emission sources. Consequently, the ground-level concentrations predicted by the modelling are likely to be highly conservative, i.e., predicted concentrations are likely to be over-estimated, rather than under-estimated.

4 MODELLING METHODOLOGY

This assessment used a suite of modelling tools to estimate air quality impacts. TAPM and CALMET were used in combination with surface meteorological station data to generate three-dimensional meteorological fields for a representative year, 2012, and CALPUFF was used for dispersion modelling. Below is a short description of these models and their set-up for this study.

Modelling was conducted generally in accordance with the 'Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales' (NSW DECC, 2005) with the exception that TAPM-derived pseudo upper air stations were used in preference to the m3d files for 'hybrid mode' (OEH, 2011) within the CALMET configuration. During the review of model performance, the use of the m3d files in CALMET was found to significantly under-predict wind speeds and often cause artificial convergence and divergence of horizontal flows. Using TAPM upper air data at a pseudo station with local surface weather observations was found to produce more realistic wind patterns and speeds.

4.1 TAPM AND CALMET

TAPM is a three-dimensional meteorological and air pollution model produced by the CSIRO Division of Atmospheric Research. In this project, only the meteorological portion of the TAPM model was used. The TAPM meteorological model is a prognostic model that uses archived gridded global weather data to predict hourly three-dimensional weather conditions over a finer grid.

Upper air data were generated over the study region using TAPM. The TAPM-generated upper air data and observed surface meteorological data were entered into the CALMET diagnostic meteorological model, which is discussed below.

CALMET is a meteorological pre-processor that provides the meteorological inputs required to run the CALPUFF dispersion model. It creates a three-dimensional meteorological field and includes a wind field generator that takes into account slope flows, terrain effects and terrain blocking effects. CALMET produces fields of wind components, air temperature, relative humidity, mixing height and other micro-meteorological variables for each hour of the modelling period.

For this project CALMET was set up with the following parameters:

- The CALMET module was driven by surface meteorological data measured at Jabiru Airport (a Bureau of Meteorology site, approximately 4 kilometres from the mine) and upper air data generated by TAPM (centre of the existing Ranger mine).
- The CALMET setup included a horizontal domain 18 km by 18 km, at a grid resolution of 150 m.
- The CALMET setup used Shuttle Radar Topography Mission (SRTM 3) terrain data with a resolution of approximately 90 m for most of the domain. Within the site boundary, the SRTM 3 terrain data was modified based on predicted terrain data provided by ERA. These modifications to terrain are representative of what Ranger topography will look like at the proposed commencement time of the Project. These predictions are based on the transfer of waste rock material from existing stockpiles to Pit 3 as a component of progressive rehabilitation at Ranger.

- The CALMET setup used customised land use data reflecting the land use in the Project area and its surrounding environment. It introduced a customised forest type to reflect the sparse tree coverage in the forest land nearby. The new category is named as category 44, with parameters based on flux measurements over Northern Territory savannah (D'Abreton, 2011), as per Table 4.

Table 4 – CALPUFF land use category parameters

Parameter	Explanation	Value
Surface roughness	A measure of surface texture, a function of vegetation and surface type; affects turbulence	0.75
Albedo	Fraction of incoming solar radiation reflected back to space and not absorbed into earth-atmosphere system	0.2
Bowen ratio	Ratio of sensible heat flux to latent heat flux; reflects heating vs evaporation and affects temperature and turbulence	1.5
Soil heat flux	Measure of the energy heating and cooling the ground; affects turbulence.	0.15
Anthropogenic heat flux	Waste heat entering the atmosphere from human activities, particularly combustion	0
Leaf area index	A measure of the density of vegetation canopies	2.2

Rainfall data observed at Jabiru Airport, including rainfall types and rainfall intensity, were provided as model input.

4.2 CALPUFF

CALPUFF is an advanced and versatile air quality model developed in the US for regulatory purposes, now used in over 100 countries. It has been widely adopted in Australia over the past 10-15 years and is specifically designed to better cope with the effects of complex meteorological conditions on plume dispersion than previous types of model. It can account for localised deviation of winds caused by terrain, and can also deal with calms, both of which are critical to many air quality assessments.

CALPUFF (Scire et al. 2000) is a so-called puff model, which mathematically breaks plumes into many smaller puffs. These puffs are then tracked in 3-D space as they rise due to buoyancy (if relevant), are transported by wind, are spread out by turbulence, and are deposited on the earth's surface. The model calculates the total effect of perhaps many thousands of puffs that are in the model space at any given time. CALPUFF can simulate the effects of plume chemical reactions, particle deposition, enhanced turbulence affecting plumes from stacks when they are caught in building wakes, and a range of other detailed effects that are designed to improve the model's performance.

5 METEOROLOGY

5.1 CLIMATE OF THE AREA

The Project site is located in the Northern Territory, about 70 km inland. Weather data collected at Jabiru Airport by the Bureau of Meteorology (BoM) since 1984 have been used to describe the climate for the Project area. Key climate statistics are presented in Table 5.

The climate of Jabiru is classified as tropical monsoonal, marked by distinct wet and dry seasons and relatively high temperatures year round (Sturman & Tapper, 2006; Australian Bureau of Meteorology Staff, 2008). The wet season extends from December to March, the dry season from May to October, with the intermediate months of November and April regarded as transitional. Seasonal changes in rainfall and humidity are more significant in this climate than changes in temperature. The monsoonal regime is also associated with distinct seasonal changes in wind direction, between the humid northwest monsoon flow in the height of the wet season and the south-easterly winds that bring low humidity in the dry season.

Daily maximum temperatures are above 30°C most days of the year, occasionally exceeding 40°C in October and November during the build-up to the wet season. Daytime temperatures are often reduced during the peak monsoon period, owing to heavy cloud cover and high humidity. Daily minimum temperatures are at their highest in the early wet season (December) and the lowest values are in the mid dry season (June and July), when cloud cover and humidity are low.

Median annual rainfall is approximately 1,600 mm, of which about 90% falls in the 5 months between November and March (see Table 5). During this period there is a high risk of tropical cyclones and other intense weather systems that bring flooding. During the dry season, there are extended periods without rain and surface conditions become very dry. Fire is a feature of the environment during the dry season, with lightning-induced wildfires a risk late in the season, particularly if early season burning is absent or reduced (Price *et al*., 2012).

Table 5 - Summary of Long-term Climate for Jabiru

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean max temp. (ºC)	33.6	33.1	33.5	34.5	33.5	31.6	31.9	33.7	36.2	37.6	36.9	35.0	34.3
Highest temp. (ºC)	38.0	37.7	38.0	38.0	37.6	36.0	36.1	38.0	40.0	41.6	42.4	39.6	42.4
Mean min temp. (ºC)	24.6	24.5	24.3	23.5	21.8	19.1	18.5	19.1	21.6	23.9	24.9	24.9	22.6
Lowest temp. (ºC)	20.5	20.6	20.4	16.0	13.9	9.9	8.8	12.0	12.0	13.7	19.0	21.1	8.8
Median monthly rainfall (mm)	350	363	324	85.3	12.6	1.1	3.0	2.8	6.3	41.2	143	235	1,580
Highest monthly rainfall (mm)	611	801	1140	351	89.6	11.8	47.4	60.4	81.2	270	33	459	2,620
Highest daily rainfall (mm)	139	190	393	110	36.6	11.8	46.2	34.0	62.0	92.0	125	88.6	393
Number of rain days (>1 mm)	18.4	18.3	17.9	6.0	1.5	0.1	0.2	0.2	0.4	2.7	9.5	13.6	88.8
Mean 9am relative humidity (%)	82	85	81	70	62	57	56	55	59	62	68	75	68
Mean 3pm relative humidity (%)	65	66	58	44	37	34	30	26	25	28	40	54	42
Daily evaporation (mm)	5.8	5.7	5.6	6.7	7.0	6.7	7.0	8.0	9.1	9.5	8.0	6.8	7.2
Mean 9am wind speed (km/h)	5.7	5.0	5.0	6.9	9.4	10.5	9.6	8.1	6.6	6.2	5.6	5.8	7.0
Mean 3am wind speed (km/h)	10.2	10.0	9.4	10.6	10.9	10.8	11.5	11.2	11.6	10.8	9.5	9.7	10.5

5.1 METEOROLOGICAL DATA SELECTION

Meteorology and emissions determine ambient air quality, so it is important that meteorological characteristics are well represented in an air quality model. Even with constant emissions, air quality can vary greatly over time as a result of changing weather conditions. For some types of emission, such as wind-generated dust, weather conditions also affect the emission rates.

To model the dispersion of emissions from a specific source or project, it is necessary to use a set of meteorological conditions that includes the range of atmospheric dispersion parameters that can be expected in a typical year. Year-to-year variations in weather may lead to changes in air quality impacts. The significance of such variations differs according to location and the type of impact being assessed.

The meteorological year selected for modelling has been determined by analysing key meteorological factors such as temperature, wind direction, wind strength and rainfall using five years of meteorological data. This approach is particularly appropriate where key meteorological parameters do not vary significantly from one year to the next. This is the case at the Ranger mine. To place the meteorological factors in context, there are many other sources of model uncertainty, such as emission rate estimation and inherent uncertainties associated with the way models are formulated. Hence, one year of meteorology, if selected appropriately, is likely to provide a basis for assessment that is within acceptable bounds of uncertainty when all contributing factors to uncertainty are considered.

For this project, 2012 was selected as a representative year for meteorology, based on statistical analysis of data measured over several years. The evaluation was based on Jabiru Airport weather data for 2008-2012. Daily maximum and minimum temperatures, and wind speed data at 9am and 3pm, were analysed as they have an influence on plume dispersion and are readily available parameters. Student’s t-test[3] was applied to annual averages of monthly statistics to assess whether differences from the five-year average were significant at the 5% level. All years were acceptable based on these parameters. Finally, rainfall was considered in the selection of a modelling year. The year 2012 was chosen as it shows a typical seasonal rainfall distribution and the annual total is within one standard deviation of the long-term mean. This indicates that it is within the typical range of year-to-year variations and hence can be regarded as representative.

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[3] Student's t-test is a statistical hypothesis test that can be used to determine if two sets of data are significantly different from each other.

5.2 DISPERSION METEOROLOGY

Meteorological data for 2012 were used in conjunction with CALPUFF to predict ground-level concentrations of emissions associated with the project.

Features of the meteorology are described below based on data taken from the CALMET model output.

5.2.1 Rainfall

Rainfall affects wet deposition of particles and gases as well as the surface moisture conditions that affect wind-blown particle emissions. During 2012, the total rainfall recorded at Jabiru airport was 1,360 mm. Rainfall data are presented in Figure 2, which shows an extended rainless period from mid-May to late September, and rainfall events reaching maximum frequency from January to March and from mid-November onwards.

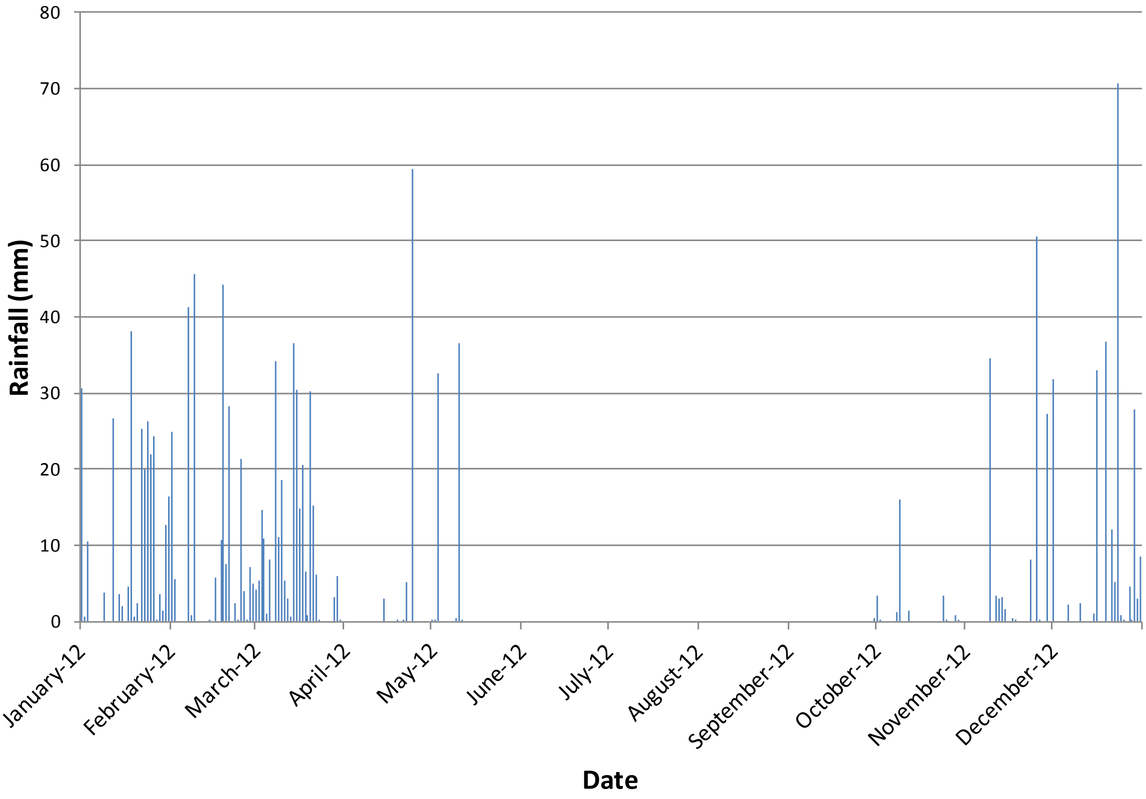


Figure 2 - Rainfall in 2012 (Recorded at Jabiru Airport)

5.2.2 Wind

Wind speed and direction are highly important influences on plume dispersion. Wind direction dictates the direction in which the plume travels. Thus, over a long period, variations in wind direction determine the spatial pattern of average ground-level concentrations. Wind speed influences the initial dilution of the plume as it leaves the source and also affects the plume rise from buoyant sources, with higher wind speeds resulting in smaller plume rise. Wind speed also has a strong influence on the erosion of particles from dry, exposed surfaces. Broadly, higher wind speeds result in lower ground-level concentrations unless wind erosion is a significant factor.

The 2012 wind data were extracted from the CALMET dataset for the site and summarised in the form of wind roses. Wind roses are commonly used to display the frequency distributions of wind direction and wind speed. In these figures, wind direction (from which wind blows) is classified into 16 compass directions, moving clockwise from north as: north (N), north-northeast (NNE), northeast (NE), east-northeast (ENE), east (E), east-southeast (ESE), southeast (SE), south-southeast (SSE), south (S), south-southwest (SSW), southwest (SW), west-southwest (WSW), west (W), west-northwest (WNW), northwest (NW), and north-northwest (NNW). The coloured sections of the wind roses show the wind speed distribution, i.e. proportion of time in each wind speed range.

The annual average wind rose is plotted in Figure 3. Diurnal and seasonal patterns are presented in Figure 4, Figure 5, Figure 6 and Figure 7. Wind roses show the following wind characteristics at the project site:

- For all hours, the most dominant wind direction is ESE, followed by E and SE. This reflects the dominance of trade wind flows, especially during the early dry season (refer to Figure 3).
- Wind rose plots for the period April to August show persistent trade wind flow predominantly from ESE, followed by E and SE. During this period, wind rarely has a westerly component (refer to Figure 4).
- Wind rose plots for the periods of January to March and September to December show more variable wind directions, with increased frequency from N, NW, W and SW (refer to Figure 5). Beginning around September, strong heating of the land in northern Australia begins to change pressure and wind patterns leading up to the wet season.
- From April to August, steady trade winds from ESE dominate both day and night hours, with more calms at night (refer to Figure 6).
- From January to March and September to December, there is greater diurnal wind variation. During the afternoon and evening, predominant wind directions are from the northern sector, reflecting both seabreeze and monsoonal effects, and there is a significant westerly component during the daytime. From midnight to 6 am, there is a high frequency of calms and overall during these months wind directions are far more variable than in the early to mid dry season (refer to Figure 7).

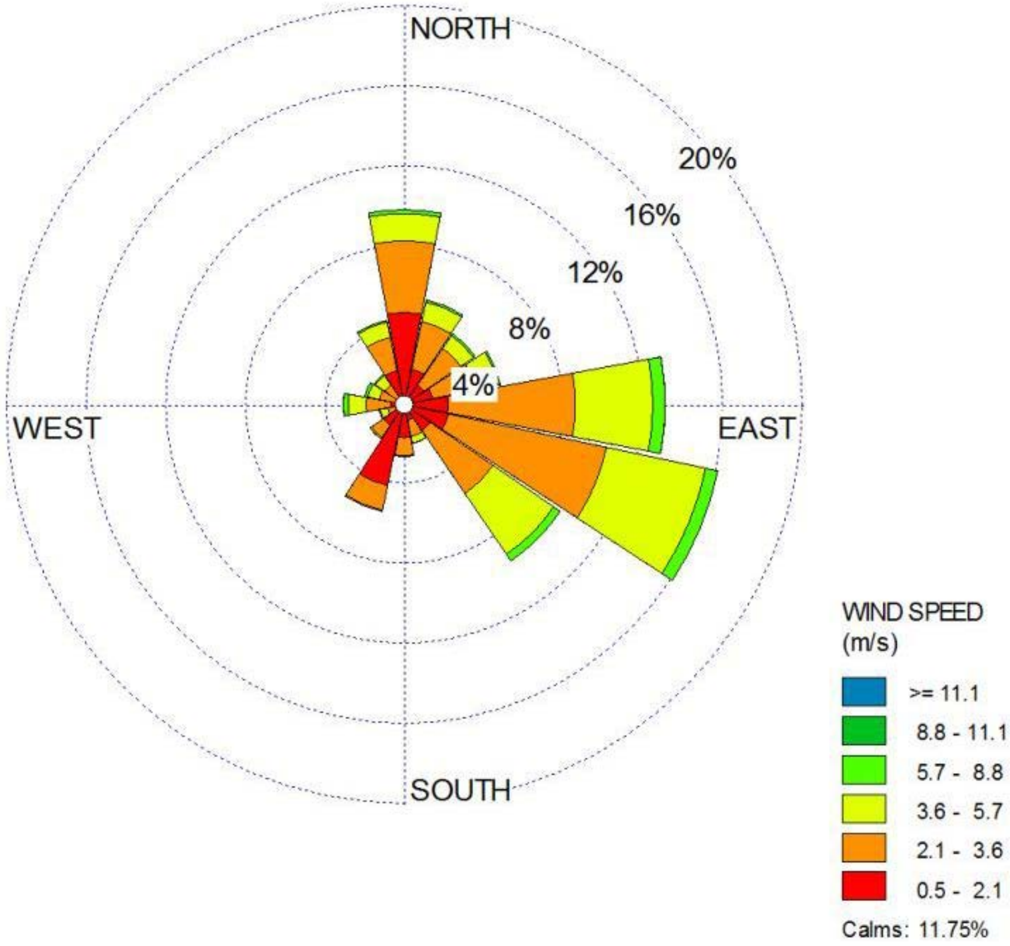


Figure 3 – Annual Wind Rose for all Hours

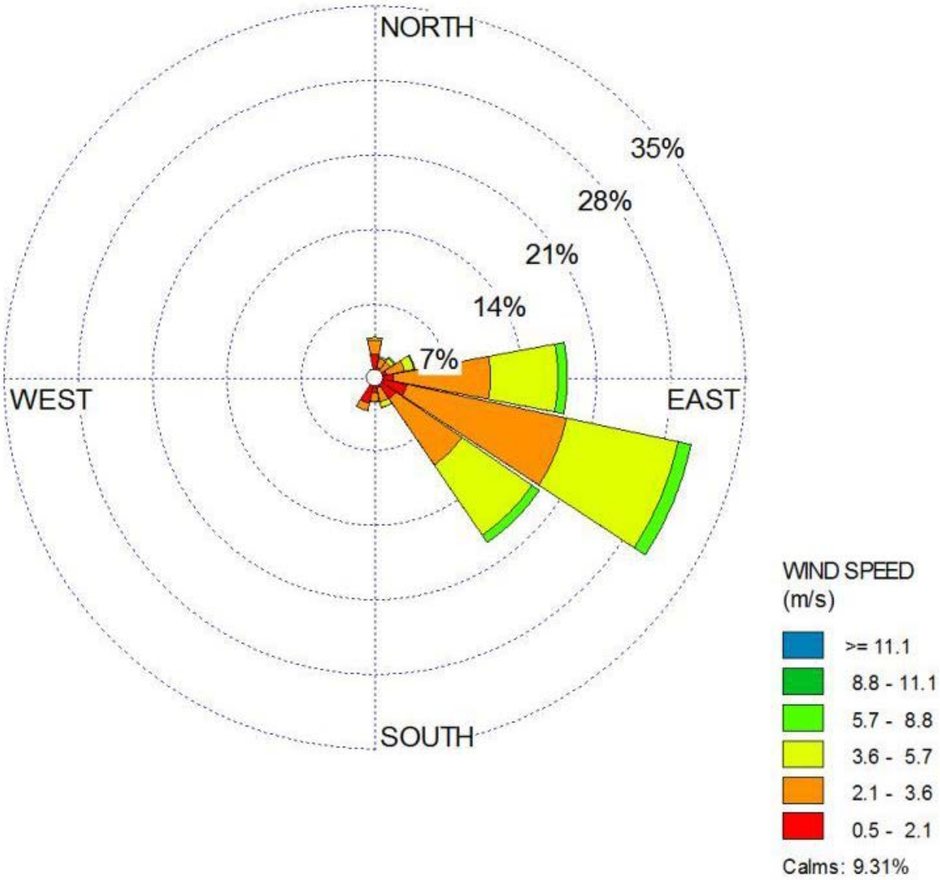


Figure 4 – Wind Rose for all Hours for the Period April – August 2012

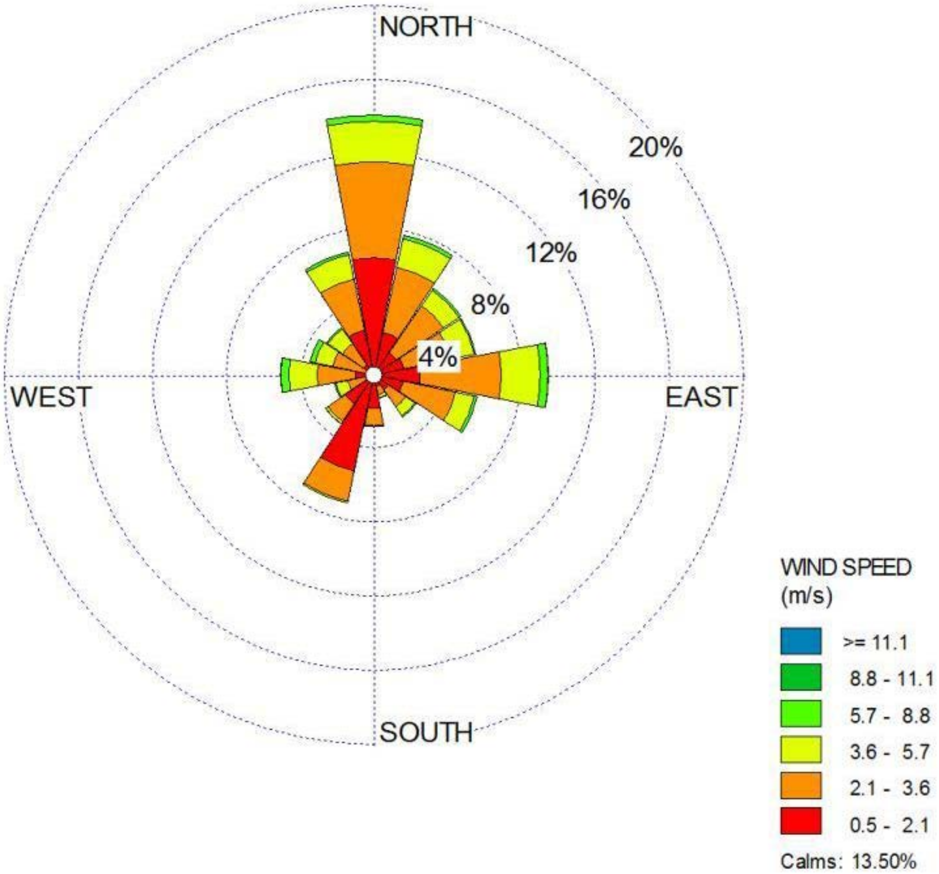
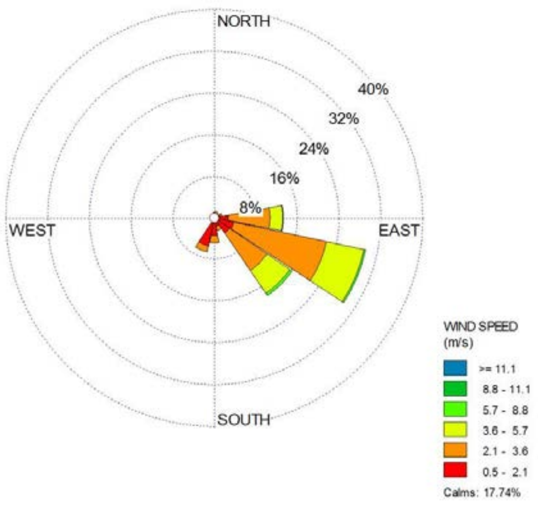
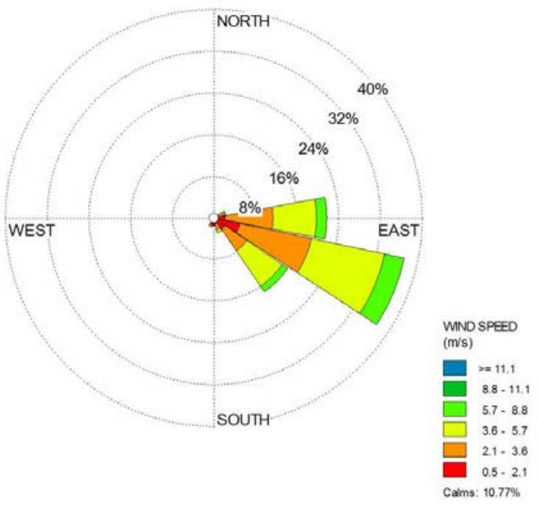


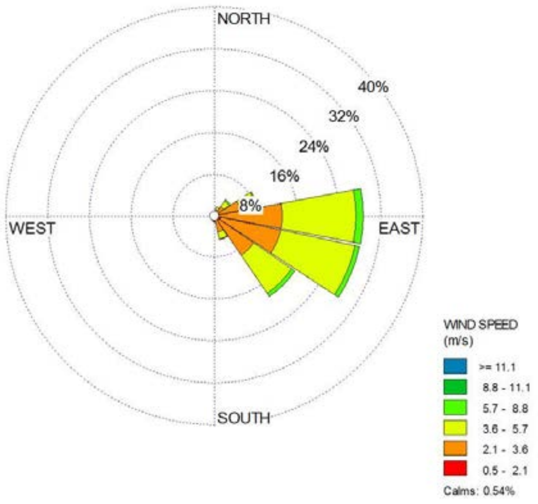
Figure 5 – Wind Rose for all Hours for January – March and September - December 2012



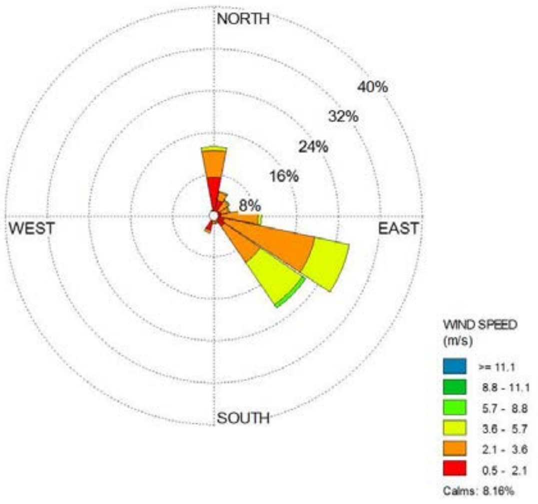
00-06 hours



06-12 hours

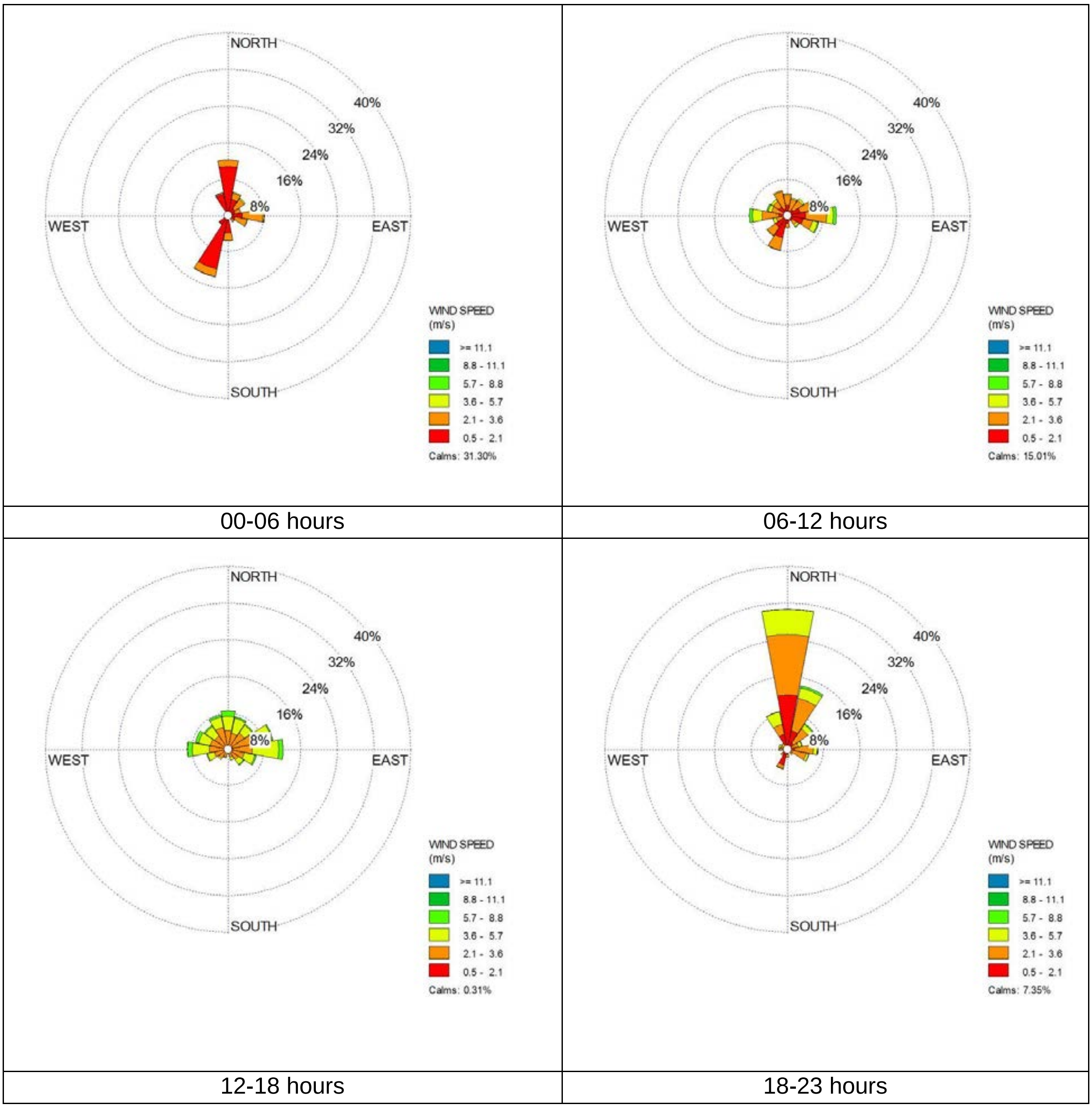


12-18 hours



18-23 hours

Figure 6 – Wind Rose by Hour of the Day for April – August 2012



00-06 hours

06-12 hours

12-18 hours

18-23 hours

Figure 7 – Wind Rose by Hour of the Day for January – March and September – December 2012

5.2.3 Mixing Height

Mixing height is the depth of the layer of turbulent mixing that extends upward from the ground. It is a product of two drivers: mechanical turbulence due to friction between moving air and the ground, and convective turbulence generated by heating of the surface. The mixing height denotes the upper limit of vertical diffusion or mixing of a plume, and hence defines the potential volume of air that a plume can be diluted into. Generally mixing height is very low during the night, as radiative surface cooling makes the air more stable and less turbulent. During the daytime, the sun heats the ground surface, causing turbulent convective eddies to develop. With increasing heating the mixing height grows, becoming highest in the mid afternoon before a rapid decrease around dusk.

Mixing height data were extracted at the Project site from CALMET output, and the summary data by hour of the day are presented in Figure 8. On average, the mixing height reached the maximum around 3 pm, with an average height of about 2,000 m.

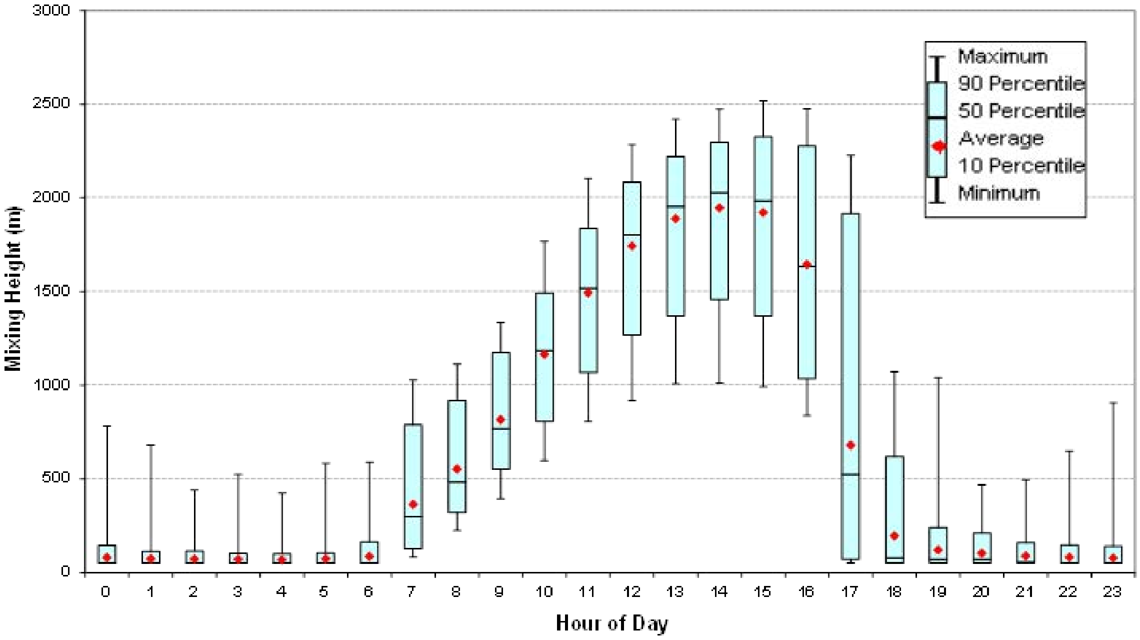


Figure 8 - Mixing Height by Hour of the Day

5.2.4 Stability Class

Atmospheric turbulence is an important factor in plume dispersion. Stability of the atmosphere refers to temperature changes with height, and is an indicator of turbulence. Turbulence mixes a plume with surrounding air, reducing the concentration of the plume material. When turbulence is stronger, the plume is mixed and diluted more rapidly. Weak turbulence inhibits this mixing, resulting in more concentrated, narrower plumes.

A widely-used stability classification method is the Pasquill-Gifford scheme, which describes stability in classes A to F. Class A is described as highly unstable and occurs when there is strong heating of the surface and light winds, leading to intense turbulence and rapid plume dilution. At the other extreme, class F denotes very stable conditions associated with strong surface temperature inversions and light winds, which commonly occur under clear skies at night and in the early morning.

Intermediate stability classes grade from moderately unstable (B), through neutral (D) to slightly stable (E). Whilst classes A and F are strongly associated with clear skies, class D is linked to windy and/or cloudy weather, as well as short periods around sunset and sunrise when surface heating or cooling is small. As a general rule, unstable (also known as convective) conditions dominate during the daytime and stable conditions are dominant at night. This diurnal pattern is most pronounced over land when there is relatively little cloud cover and light to moderate winds.

Stability class data were extracted from CALMET output for the Project site. A plot of the stability class frequency is presented in Figure 9. It shows that stable conditions (classes E and F) occur just under 50% of the time, which is typical for locations away from the immediate coastline.

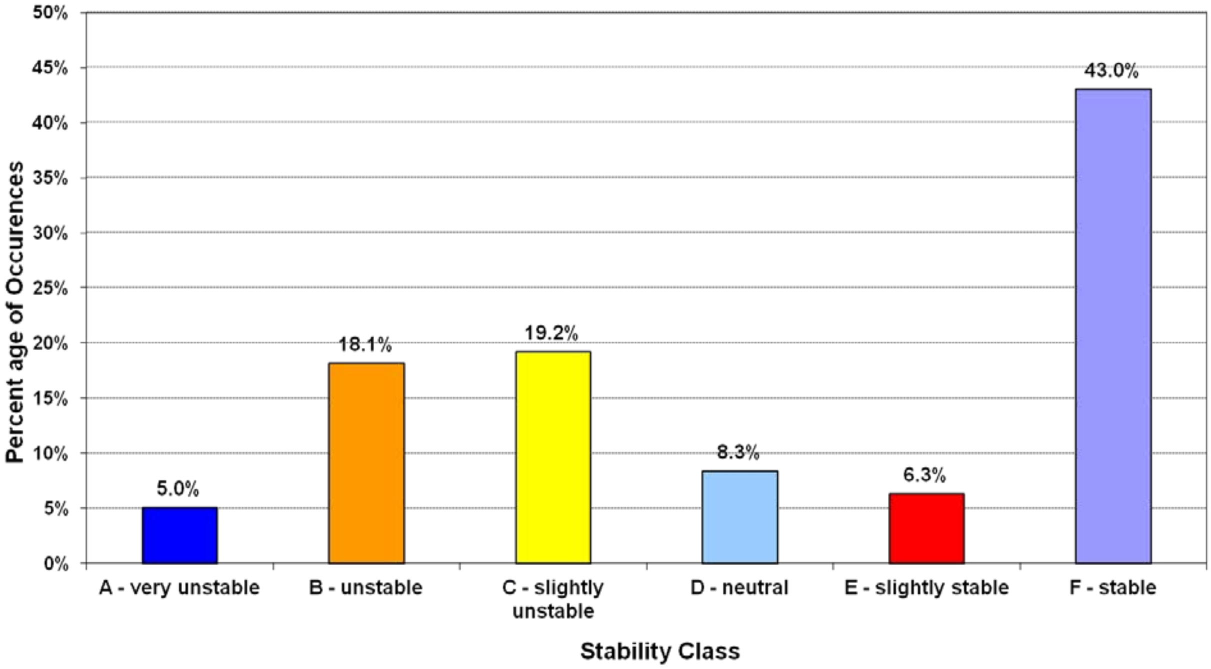


Figure 9 - Frequencies of Stability Class

A more accurate turbulence scheme within CALPUFF, based on micrometeorological parameters derived from Boundary Layer Similarity Theory[4], was used in the dispersion modelling for this assessment. In CALPUFF, Pasquill Gifford (P-G) stability classes are replaced by a more refined measure of stability, the Monin-Obukhov length, which is used to describe the effects of buoyancy on turbulent flows, particularly in the lower tenth of the atmospheric boundary layer. The Monin-Obukhov length was an important concept behind the development of Similarity Theory, and is one of a number of measures of atmospheric behaviour that are used together to describe the important aspects of the atmosphere that affect the transfer of energy and mass between the earth's surface and the atmosphere, and within the atmosphere. This scheme is more sophisticated than the P-G stability classes, and allows a continuum of values to be calculated and used in the model, instead of only the six P-G categories.

6 EMISSIONS

6.1 EMISSION ESTIMATION METHODOLOGIES

The methodology used to estimate emissions from each source is detailed in Appendix A. The emission estimates are based on widely used and accepted methods contained in guidance documents from the National Pollutant Inventory and the United States Environment Protection Agency. Where possible, emissions have been derived using site-specific data. Control factors have been applied to some sources based on ERA's intended practices, in order to develop a representative emission inventory. In some cases, assumptions are required in order to estimate the emissions. In these cases, conservative assumptions that are likely to lead to over-prediction of impacts, rather than under-prediction, have been made. For example, no natural control through precipitation has been included for any emission source.

6.2 EMISSION INVENTORY

6.2.1 Existing Emissions

The emissions calculated for each existing emission source are presented in Table 6. These sources are associated with Ranger operations in the absence of the Project. The estimates assume that the emissions are released continuously.

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[4] Often simply referred to as Similarity Theory

Table 6 – Existing Emissions Inventory

Source	TSP (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	NO_x (g/s)	SO_2 (g/s)
Paved Roads					
Paved Roads	0.018	0.0034	0.00082	-	-
Ore Stockpile					
Truck Dumping	0.150	0.054	0.0082	-	-
Loading	0.400	0.190	0.057	-	-
Wind Erosion	0.310	0.160	0.033	-	-
Total for Ore Stockpile	0.860	0.400	0.098	-	-
Waste Rock Stockpiles					
Loading – Stockpile B	0.32	0.15	0.046	-	-
Wind Erosion – Stockpile A	0.56	0.28	0.060	-	-
Wind Erosion – Stockpile B	1.2	0.59	0.13	-	-
Wind Erosion – Stockpile C	0.15	0.075	0.016	-	-
Total for Waste Rock Stockpiles	2.2	1.1	0.25	-	-
Crushing/Screening Plant[a]					
Dumping to Primary Crusher	1.6	0.77	0.12	-	-
Primary Crusher Scrubber	0.39	0.39	0.39	-	-
Coarse Ore Reclaim Scrubber	0.075	0.075	0.075	-	-
Fine Crushing Scrubber 1	0.65	0.65	0.65	-	-
Fine Crushing Scrubber 1	0.79	0.79	0.79	-	-
Ore Sorter	0.010	0.0076	0.0076	-	-
Total for Crushing/Screening Plant	3.5	2.7	2.0	-	-
Unpaved Roads					
Unpaved Roads	0.74	0.22	0.083	-	-
Surface HME (fuel combustion)					
Surface HME	0.34	0.34	0.31	4.3	0.0023
Diesel Fired Boiler[b] (fuel combustion)					
Diesel Fired Boiler	0.053	0.053	0.053	1.0	0.0042
Waste Heat Boilers[b] (fuel combustion)					
Waste Heat Boiler 1-8 (each)	0.022	0.022	0.022	3.3	0.0012
Total for Waste Heat Boilers	0.18	0.18	0.18	27	0.010
Power Station (fuel combustion)					
Power station	0.36	0.12	0.12	55	0.019

a. Crushing and screening plant will be utilised for both existing Ranger operations and the Project
b. Component of the brine concentrator water treatment plant

6.2.2 Incremental Emissions

Incremental emissions are the additional emissions associated with new or modified sources. The emissions calculated for each above-ground incremental (Project) emission source are presented in Table 7, and the underground emission sources are presented in Table 8. Note that the emissions from each source are assumed to be released continuously.

Table 7 – Incremental Emissions Inventory - Aboveground

Source	TSP (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	NO_x (g/s)	SO_2 (g/s)
Backfill Plant					
Batching Process Operations	0.031	0.016	0.016	-	-
Wind Erosion (aggregate stockpile)	0.0090	0.0045	0.00068	-	-
Aggregate Dumping	0.19	0.068	0.010	-	-
Total for Backfill Plant	0.23	0.088	0.027	-	-
Truck Dumping					
Truck Dumping	0.61	0.22	0.033	-	-
Waste Rock Stockpile					
Truck Dumping	0.083	0.030	0.0045	-	-
Bulldozing	0.11	0.026	0.0039	-	-
Wind Erosion	0.12	0.061	0.018	-	-
Total for Waste Rock Stockpile	0.32	0.12	0.027	-	-
Crushing/Screening Plant					
Crushing Ore	1.3	0.13	0.023	-	-
Crushing Aggregate	1.6	0.16	0.028	-	-
Unloading Ore	0.15	0.054	0.0082	-	-
Loading Ore	0.63	0.30	0.046	-	-
Loading Aggregate	0.79	0.38	0.057	-	-
Total for Crushing/Screening Plant	4.4	1.0	0.16		
Unpaved Roads					
Ore from portal to ore stockpile	1.5	0.46	0.17	-	-
Waste rock from portal to waste rock stockpile	0.085	0.025	0.0095	-	-
Ore from portal to mobile crusher/ore sorter	0.41	0.12	0.046	-	-
Aggregate from mobile crusher to backfill plant	0.65	0.19	0.072	-	-
Shotcrete from backfill plant to portal	0.046	0.014	0.0052	-	-
Total for Unpaved Roads	2.7	0.82	0.31	-	-
Surface HME (fuel combustion)					
Surface HME	0.0021	0.0021	0.0019	0.26	0.00014
Power Station (fuel combustion)					
Power station	0.036	0.036	0.036	27	0.0084

Table 8 – Incremental Emissions Inventory - Underground

Source	TSP (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)	NO_x (g/s)	SO_2 (g/s)	Radon (Bq/s)
Explosive Combustion (blasting)						
Explosive Combustion (blasting)	-	-	-	0.16	0.0011	-
Radon						
Radon	-	-	-	-	-	1,000,000
Fuel Combustion (HME & Light Vehicles)						
Underground HME	0.021	0.021	0.019	2.6	0.0014	-
Underground Light Vehicles	0.0016	0.0016	0.0015	0.0059	0.000011	-
Total for Fuel Combustion	0.023	0.023	0.021	2.6	0.0014	-
Mining (ore/stope related)						
Loading	0.63	0.30	0.046	-	-	-
Drilling	0.034	0.018	0.0026	-	-	-
Blasting	0.0021	0.0011	0.00080	-	-	-
Total for Mining (ore/stope related)	0.67	0.32	0.049	-	-	-
Mining (waste rock/development related)						
Loading	0.087	0.042	0.0063	-	-	-
Drilling	0.84	0.44	0.066	-	-	-
Blasting	0.0029	0.0015	0.0011	-	-	-
Grading	0.0026	0.0012	0.00018	-	-	-
Total for Mining (waste rock/development related)	0.93	0.49	0.074	-	-	-
Unpaved Roads						
Waste rock from underground to portal	0.45	0.14	0.051	-	-	-
Ore from underground to portal	3.3	0.98	0.37	-	-	-
Light vehicles 4WD	2.3	0.68	0.25	-	-	-
IT vehicle	0.15	0.045	0.017	-	-	-
Shotcreter	0.15	0.045	0.017	-	-	-
Shotcrete Underground (Agi Truck)	0.37	0.11	0.041	-	-	-
Total for Unpaved Roads	6.7	2.0	0.75	-	-	-

7 MODEL INPUTS

7.1 SOURCE CHARACTERISTICS

The source parameters applied in the CALPUFF dispersion model are discussed in the following sections. The locations of predominant emission point sources associated with both existing and Project infrastructure are illustrated in Figure 10.

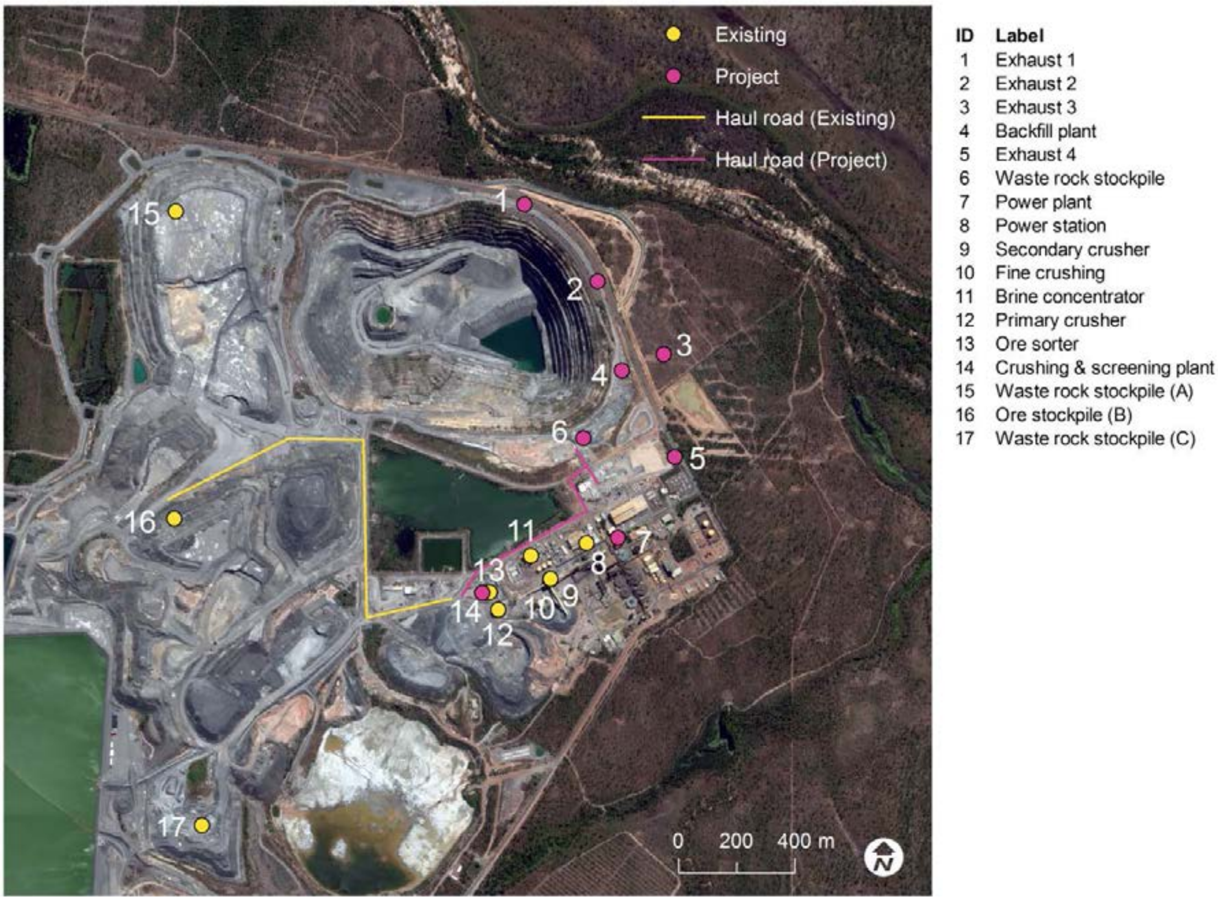

Figure 10 - Predominant Existing and Project Emission Sources

7.1.1 Existing Emissions – Point Sources

Combustion products are released from a number of stacks associated with power generation units at the currently operating Ranger uranium mine. Dust emissions associated with crushing/screening operations are also released through several scrubber stacks. The source characteristics of these release points are summarised in Appendix B, Table 30.

7.1.2 Existing Emissions – Area Sources

Wheel-generated dust emissions are produced along a haul road between Stockpile B and the primary crusher. To model these emissions, the haul road is split into many small sections, and a portion of the emissions attributed to each area. Dust emissions associated with wind erosion of stockpiles are characterised by a single large area for each stockpile. Emissions from paved roads are characterised by a single source covering the paved area of the plant. The source characteristics and their coordinates associated with these areas are summarised in Appendix B; Table 31 and Table 32 respectively.

7.1.3 Existing Emissions – Volume Sources

Dust emissions are released from a number of sources, such as loading and dumping operations, that are neither stacks nor large areas. These sources are modelled as volume sources in CALPUFF. The source characteristics of these activities are summarised in Appendix B; Table 33.

7.1.4 Incremental Emissions – Point Sources

Project emissions associated with exhaust ventilation have been based on six exhaust stacks along its length, at four different locations[5]. The northern and southern locations (exhaust 1 and exhaust 4) have a single ventilation stack at each location, while the two central locations (exhaust 2 and exhaust 3) each have twinned ventilation exhausts, which are approximately 20 m apart. Point sources located close together can be modelled as a single source, as long as the source characteristics are modified correctly to obtain appropriate plume rise enhancement. As such, the exhaust 2 and exhaust 3 stacks were modelled as a single source at each location using an equivalent diameter based on the diameter of each stack. Along with these sources, a new power generation system will be required to meet the power demands of the Project. The source characteristics of the power station stack and the exhaust stacks are summarised in Appendix B, Table 34.

7.1.5 Incremental Emissions – Area Sources

Wheel-generated dust emissions are produced along haul roads between the mine portal, the backfill plant, the ore stockpile and the crushing and screening plant. To model these emissions, the haul roads are split into many small sections, and the emissions attributed to each area. Dust emissions associated with wind erosion of the Project waste rock stockpile are characterised by a single large area for the stockpile. The source characteristics of these areas are summarised in Table 35, and the coordinates are presented in Table 36.

7.1.6 Incremental Emissions – Volume Sources

The estimated parameters of incremental volume sources of dust emissions are presented in Appendix B, Table 37.

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[5] This configuration is based on a particular mine plan, taking into account maximum mine volume and flow distribution from each ventilation stack to meet underground air quality requirements. The final ventilation arrangement will be subject to detailed engineering design.

7.2 NO_X CHEMISTRY

One of the most common atmospheric chemistry issues in air quality modelling is estimating NO_2 (nitrogen dioxide) from modelled NO_X (oxides of nitrogen) concentrations. The amount of NO_2 in the exhaust gas as it is released from a combustion source is typically in the order of 5 to 10% of total NO_X, and the remainder is mostly nitric oxide (NO), which is much less toxic. The key compound of concern in air quality impact assessment is NO_2.

As a plume ages after its release into the atmosphere, its NO component is oxidised to NO_2 at a rate that varies greatly depending on ambient ozone (O_3) concentrations, the intensity of turbulence and other factors. To estimate the conversion of NO to NO_2 that occurs after the exhaust gases are discharged, the following methods are available:

- Total conversion method (Tier 1 or screening):
  - In this very conservative screening approach, predicted ground-level concentrations of total NO_x are assumed to exist as 100% NO_2 instantaneously, i.e., at release.

- US EPA Tier 2 analysis:
  - This conservative method assumes a 75% conversion of NO_x to NO_2 (US EPA, 2005), which also occurs instantaneously.

- Ozone Limited Method (OLM):
  - The OLM is based on the assumption that approximately 10% of the NO_x emissions are generated as NO_2 (AE, 2003). If the O_3 concentration is greater than 90% of the predicted NO_x concentrations, all the NO_x is assumed to be converted to NO_2, otherwise $NO_2 = O_3 + 0.1* NO_x$. The conversion is assumed to occur instantaneously after release. The OLM method is often used in remote airsheds with little likelihood of smog-related issues, where the Tier 1 and Tier 2 screening methods indicate that less conservative assessments are required.

- Ambient ratio method (ARM):
  - If there is at least 1 year of monitoring data available for NO_x and NO_2 within the airshed, an empirical NO_2:NO_x relationship can be derived and used as an alternative to the ozone limiting method (AE, 2003; US EPA, 2005).

- Reactive Plume Modelling:
  - This approach is more realistic, as it takes into account the time taken for NO to be converted to NO_2. A detailed analysis of NO_x conversion was presented by Arellano (Arellano et al. 1990), who went on to develop a chemically reactive plume model (CRPM) based on theory and measurements. This approach requires detailed data inputs for regional emissions and is usually used for regional inventory modelling.

To produce highly conservative results to compare to the guidelines, the existing and incremental impacts of NO_x were assessed individually using the Tier 1 method. To produce more realistic, but still conservative, results for the cumulative impact assessment, i.e., existing plus incremental emissions, the cumulative NO_2 concentrations were predicted using the US EPA Tier 2 method.

The implications of the conversion method for the model results are discussed further in section 9.

7.3 DEPOSITION MODELLING

Dry deposition of particles downwind of a surface source of dust, such as a haul road, stockpile or crusher, is dominated by the gravitational settling of larger particles, typically more than 20 µm in aerodynamic diameter. Gravitational settling of a particle depends on its deposition velocity, which is the distance a particle travels toward the ground in a unit of time, after accounting for deviations caused by turbulence. The deposition velocity (or settling velocity) of a particle depends on the particle size and density, as well as properties of the atmosphere including density and viscosity.

Particle deposition in CALPUFF is predicted by a resistance model, which allows for the effects of gravitational settling and a set of other factors. For this assessment, a particle aerodynamic diameter of 30 µm and unit density (1 g/m^3) was assumed to estimate the deposition velocity. These values are often used in the absence of site-specific data in order to estimate deposition velocity of mechanically generated dust.

Wet deposition was excluded in this assessment, and is inconsequential for dust deposition modelling.

8 DISPERSION MODELLING RESULTS

The predicted ground-level concentrations of each substance included in the model at the 11 defined receptors are presented in Table 9 to Table 19. The results indicate that for most substances the ground level concentrations at all receptors are within relevant guideline values. It should be noted that not all receptor types had available national guidelines, for example the NEPM guidelines only apply to residential areas. Many of the receptors included by ERA in this assessment were for purposes other than comparison with national guidelines. Discussion on the results for these receptors will be undertaken by ERA in other sections of the Environmental Impact Statement.

Note that to determine cumulative results, the output from the existing and incremental models are combined for each time period. So the cumulative 24-hr averaged PM_{10} concentration for the 1st of July is the sum of the existing and incremental result for the 1st of July. As such, the cumulative result is not always the sum of the maximum predicted concentrations for existing and incremental (i.e., the maximum result for the existing model may be on a different day or hour to the maximum result for the incremental model).

At face value, the 1-hr average concentrations of NO_2 are shown to exceed the guideline at Ranger mine village (contractor camp), both for existing and cumulative impacts. To analyse these results further, the top ten predicted hourly-averaged concentrations at the receptor are presented in Table 20 for existing emissions and Table 21 for cumulative impacts. Appendix C presents the predicted concentrations of each substance across the study area in the form of contour plots. The issue of NO to NO_2 conversion is addressed further in Section 9.

Table 9 – Maximum Predicted 24-hr Averaged $PM_{2.5}$ Concentrations

ID	Relevant Receptor	Maximum 24-hr Averaged $PM_{2.5}$ Concentration		
		Existing (µg/m³)	Incremental (µg/m³)	Cumulative (µg/m³)
1	Mudginberri	0.22	0.070	0.29
2	009 Camp	0.82	0.24	0.94
3	Jabiru	0.96	0.33	1.3
4	Jabiru Airport (and businesses)	3.7	1.3	4.9
5	Ranger mine village (contractor camp)	8.3	2.1	9.9
Guideline: 25 µg/m³				

Table 10 – Predicted Annual Averaged $PM_{2.5}$ Concentrations

ID	Relevant Receptor	Annual Averaged $PM_{2.5}$ Concentration		
		Existing (µg/m³)	Incremental (µg/m³)	Cumulative (µg/m³)
1	Mudginberri	0.027	0.011	0.039
2	009 Camp	0.093	0.038	0.13
3	Jabiru	0.13	0.054	0.19
4	Jabiru Airport (and businesses)	0.71	0.29	1.0
5	Ranger mine village (contractor camp)	1.7	0.52	2.3
Guideline: 8 µg/m³				

Table 11 – Maximum Predicted 24-hr Averaged PM_{10} Concentrations

ID	Relevant Receptor	Maximum 24-hr Averaged PM_{10} Concentration		
		Existing (µg/m^3)	Incremental (µg/m^3)	Cumulative (µg/m^3)
1	Mudginberri	0.41	0.26	0.67
2	009 Camp	1.2	0.90	1.9
3	Jabiru	1.5	1.2	2.7
4	Jabiru Airport (and businesses)	6.5	4.2	10
5	Ranger mine village (contractor camp)	13	7.3	20
Guideline: 50 µg/m^3				

Table 12 – Predicted Annual Averaged Dust Deposition Rates

ID	Relevant Receptor	Annual Averaged Dust Deposition Rate		
		Existing (g/m^2/month)	Incremental (g/m^2/month)	Cumulative (g/m^2/month)
6	Mount Brockman	0.021	0.064	0.085
7	Tree Snake Dreaming	0.040	0.13	0.17
8	R34 cultural heritage site	0.12	1.1	1.2
9	Retention Pond 1	0.16	0.21	0.37
10	Magela Creek	0.092	0.30	0.40
11	Georgetown Billabong	0.035	0.099	0.14
Guideline: 4 g/m^2/month				

Table 13 – Predicted Annual Averaged TSP Concentrations

ID	Relevant Receptor	Annual Averaged TSP Concentration		
		Existing (µg/m^3)	Incremental (µg/m^3)	Cumulative (µg/m^3)
1	Mudginberri	0.015	0.031	0.046
2	009 Camp	0.063	0.10	0.17
3	Jabiru	0.090	0.20	0.29
4	Jabiru Airport (and businesses)	0.60	1.0	1.6
5	Ranger mine village (contractor camp)	1.6	1.3	2.9
6	Mount Brockman	0.14	0.51	0.65
7	Tree Snake Dreaming	0.51	1.3	1.8
8	R34 cultural heritage site	1.7	14	15
9	Retention Pond 1	1.7	2.1	3.8
10	Magela Creek	1.25	3.5	4.8
11	Georgetown Billabong	0.38	0.96	1.3
Guideline: 90 µg/m^3				

Table 14 – Maximum Predicted 1-hr Averaged SO_2 Concentrations

ID	Relevant Receptor	Maximum 1-hr Averaged SO_2 Concentration		
		Existing (µg/m^3)	Incremental (µg/m^3)	Cumulative (µg/m^3)
1	Mudginberri	0.014	0.0054	0.016
2	009 Camp	0.036	0.023	0.059
3	Jabiru	0.038	0.011	0.041
4	Jabiru Airport (and businesses)	0.079	0.026	0.099
5	Ranger mine village (contractor camp)	0.13	0.037	0.16
Guideline: 570 µg/m^3				

Table 15 – Maximum Predicted 24-hr Averaged SO_2 Concentrations

ID	Relevant Receptor	Maximum 24-hr Averaged SO_2 Concentration		
		Existing (µg/m^3)	Incremental (µg/m^3)	Cumulative (µg/m^3)
1	Mudginberri	0.0010	0.00038	0.0014
2	009 Camp	0.0037	0.0015	0.0052
3	Jabiru	0.0055	0.00085	0.0063
4	Jabiru Airport (and businesses)	0.014	0.0025	0.016
5	Ranger mine village (contractor camp)	0.021	0.0034	0.023
Guideline: 230 µg/m^3				

Table 16 – Predicted Annual Averaged SO_2 Concentrations

ID	Relevant Receptor	Annual Averaged SO_2 Concentration		
		Existing (µg/m^3)	Incremental (µg/m^3)	Cumulative (µg/m^3)
1	Mudginberri	0.00014	0.000032	0.00018
2	009 Camp	0.00045	0.000092	0.00054
3	Jabiru	0.00083	0.00018	0.0010
4	Jabiru Airport (and businesses)	0.0026	0.00056	0.0031
5	Ranger mine village (contractor camp)	0.0052	0.00080	0.0060
Guideline: 57 µg/m^3				

Table 17 – Maximum Predicted 1-hr Averaged NO_2 Concentrations

ID	Relevant Receptor	Maximum 1-hr Averaged NO_2 Concentration			
		100% Conversion NO to NO_2			75% Conversion NO to NO_2
		Existing (µg/m^3)	Incremental (µg/m^3)	Cumulative (µg/m^3)	Cumulative (µg/m^3)
1	Mudginberri	29	15	39	29
2	009 Camp	86	61	150	110
3	Jabiru	84	28	96	72
4	Jabiru Airport (and businesses)	200	74	260	190
5	Ranger mine village (contractor camp)	310	120	430	330
Guideline: 250 µg/m^3					

Table 18 – Predicted Annual Averaged NO_2 Concentrations

ID	Relevant Receptor	Annual Averaged NO_2 Concentration			
		100% Conversion NO to NO_2			75% Conversion NO to NO_2
		Existing (µg/m^3)	Incremental (µg/m^3)	Cumulative (µg/m^3)	Cumulative (µg/m^3)
1	Mudginberri	0.33	0.073	0.40	0.30
2	009 Camp	0.99	0.21	1.2	0.90
3	Jabiru	1.9	0.41	2.3	1.7
4	Jabiru Airport (and businesses)	5.7	1.2	6.9	5.1
5	Ranger mine village (contractor camp)	11	2.0	13	9.8
Guideline: 62 µg/m^3					

Table 19 – Predicted 24-hr and Annual Averaged Radon Concentrations

ID	Relevant Receptor	Incremental Radon Concentration	
		Maximum 24-hr Averaged (µg/m^3)	Annual Averaged (µg/m^3)
1	Mudginberri	0.043	0.0049
2	009 Camp	0.15	0.014
3	Jabiru	0.24	0.031
4	Jabiru Airport (and businesses)	0.65	0.097
5	Ranger mine village (contractor camp)	0.37	0.084

Table 20 – Top Ten Hourly Existing NO_2 Concentrations at Ranger Mine Village (Contractor Camp)

Rank	Predicted Ground-level Concentration (Tier 1 – 100% conversion of NO_x to NO_2) (µg/m^3)	Date of Result	Time of Result
Highest	310	6/8/2012	7:00-8:00 AM
2nd Highest	310	2/8/2012	7:00-8:00 AM
3rd Highest	270	7/8/2012	7:00-8:00 AM
4th Highest	270	25/7/2012	7:00-8:00 AM
5th Highest	240	9/8/2012	7:00-8:00 AM
6th Highest	240	9/8/2012	2:00-3:00 AM
7th Highest	230	13/7/2012	7:00-8:00 AM
8th Highest	220	12/7/2012	7:00-8:00 AM
9th Highest	220	16/8/2012	7:00-8:00 AM
10th Highest	210	11/9/2012	7:00-8:00 AM

Table 21 – Top Ten Hourly Cumulative NO_2 Concentrations at Ranger Mine Village (Contractor Camp)

Rank	Predicted Ground-level Concentration (Tier 2 – 75% conversion of NO_x to NO_2) (µg/m^3)	Date of Result	Time of Result
Highest	330	6/8/2012	7:00-8:00 AM
2nd Highest	310	2/8/2012	7:00-8:00 AM
3rd Highest	280	25/7/2012	7:00-8:00 AM
4th Highest	260	7/8/2012	7:00-8:00 AM
5th Highest	230	16/8/2012	7:00-8:00 AM
6th Highest	220	9/8/2012	7:00-8:00 AM
7th Highest	210	13/7/2012	7:00-8:00 AM
8th Highest	210	12/7/2012	7:00-8:00 AM
9th Highest	200	11/9/2012	7:00-8:00 AM
10th Highest	200	10/11/2012	6:00-7:00 AM

9 DISCUSSION

The results of the cumulative impact assessment presented in Section 8 indicate that, based on the assumptions and methods used in the modelling, there are no exceedances of the relevant guidelines for $PM_{2.5}$, PM_{10}, dust deposition, annual average NO_2, or SO_2 at the sensitive receptors around the Ranger uranium mine. Some discussion of the results for 1-hr average NO_2 concentrations follows.

The Air NEPM NO_2 1-hour goal for human health is predicted to be exceeded at the Ranger mine village (contractor camp), where the model predicts exceedance during four hours of the year. To analyse these results, the top ten predicted NO_2 concentrations at the receptor were identified (Table 21). The top eight concentrations were predicted to occur at 7:00-8:00 am in the months of July and August. These predictions are consistent with the wind roses presented in Figure 6, showing the dominant wind direction for the morning hours in July and August is from the southeast. The ninth and tenth highest values were predicted to occur in the morning, in September and November respectively. The high concentration predictions are likely attributable to fumigation events, when the plume of the power station is trapped within the growing mixing layer (Figure 8) and the turbulent convective eddies described in Section 5.2.3 bring the plume to ground while the vertical extent of mixing is still limited. The prediction of ground-level concentrations at these times is strongly influenced by the modelled mixing height, which is a factor with significant uncertainty in the model during the early morning growth period.

However, it is important to further consider the results in the context of the method used to predict the conversion of NO to NO_2. For the individual assessments (i.e., existing and incremental), the Tier 1 method was applied, yielding a 100% NO_2 to NO_x ratio from the point of release. For the cumulative assessment, Tier 2 was applied, yielding a 75% NO_2 to NO_x ratio from the point of release.

As indicated in section 7.2, the conversion of NO to NO_2 is a process that takes place over time. The rate of conversion varies in complex ways. Observations and models reviewed by the UK Environment Agency (Middleton *et al.*, 2007) and US investigators (Podrez, 2013) indicate that the methods used in this assessment have a strong tendency to over-predict NO_2 concentrations, particularly in the near-field (within 1-5 km of the source). Hence, the maximum NO_2 concentrations predicted by the methods available for this assessment may be significantly overstated, particularly at the receptors closest to the emission sources.

It should also be noted that the estimated emissions for both the existing and incremental emission inventories are conservative. Therefore, the predicted cumulative impacts are also likely to be conservative, with the results over-predicted, rather than under-predicted, at relevant receptors. Validating the model predictions against monitoring data would reduce the uncertainty attached to the model results and the associated impact assessment. A suitably validated model would then be a basis for proactive management of emissions, if required.

10 CONCLUSIONS

The dispersion model CALPUFF was used in this study to predict the existing and future ground-level concentrations associated with Project activities. The modelling approach is consistent with best practice in Australia and incorporates local meteorological and terrain conditions, and expected emissions.

The Project of itself does not exceed the assessment criteria at any of the defined receptor locations. Similarly, the results indicate that the cumulative impact of the Project and existing sources on the receptors are within the relevant guidelines for most of the selected substances, with the only exception being hourly averaged NO_2 concentrations at the Ranger mine village (contractor camp).

Existing sources of NO_2 emissions are significant contributors to predicted cumulative 1-hr averaged NO_2 emission concentrations. The Project itself, by comparison, makes a less significant contribution to the predicted 1-hr averaged NO_2 concentrations. Despite this, the 1-hr average NO_2 impact criterion is predicted to be exceeded at the Ranger mine village (contractor camp) during four hours of the year. However, the maximum concentrations may be significantly over-predicted as a result of the methods available to estimate the conversion of NO_2 from NO.

The estimated emissions for both the existing and incremental emission inventories are conservative, and therefore the cumulative impacts predicted are also likely to be conservative. Given the conservative nature of the assessment and that there are no predicted exceedances of guidelines due to the Project itself, it can be concluded that the Project will have a low impact on local air quality.

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12 APPENDIX A – EMISSION ESTIMATION

12.1 SOURCES OF EMISSIONS

The emission sources assessed for the project are outlined in Table 22 (existing) and Table 23 (incremental). The activity category of each source has been defined, which identifies the emission estimation methodology that was used to quantify the source's emissions.

Table 22 – Existing Emission Sources Assessed

Emission Source Description	Activity Category
Crushing/screening operations (primary crusher scrubber, coarse ore reclaim scrubber, fine crusher scrubber 1, fine crusher scrubber 2)	Not estimated [a]
Diesel combustion - surface HME	Miscellaneous vehicle
Diesel fired boiler	Not estimated [a]
Dumping ore to primary crusher	Not estimated [a]
Existing power station	Not estimated [a]
Ore sorter (low moisture content ore)	Screening
Ore stockpile – dumping ore	Unloading
Ore stockpile – loading ore	Loading
Ore stockpile – wind erosion	Wind erosion (active)
Stockpile A – wind erosion	Wind erosion (inactive)
Stockpile B – loading ore	Loading
Stockpile B – wind erosion (active area)	Wind erosion (active)
Stockpile B – wind erosion (inactive area)	Wind erosion (inactive)
Stockpile C – wind erosion	Wind erosion (inactive)
Waste heat boilers 1 though 8	Not estimated [a]
Wheel generated dust from paved roads throughout facility	Paved roads
Wheel generated dust from unpaved roads (hauling ore from stockpile B to ore stockpile)	Unpaved roads

a – Emission rates were provided by ERA for these sources, therefore Pacific Environment have not estimated the emissions

Table 23 - Incremental Emission Sources Assessed

Emission Source Description	Activity Category
Surface Emission Sources	
Backfill plant – aggregate unloading	Unloading
Backfill plant – batching operations	Batching operations
Backfill plant – wind erosion of aggregate stockpile	Wind erosion (batching)
Hauling (unpaved road wheel generated dust)	Unpaved roads
Mobile crusher – crushing aggregate (low moisture)	Primary crushing
Mobile crusher – crushing ore (low moisture)	Primary crushing
Mobile crusher – loading aggregate	Loading
Mobile crusher – loading ore	Loading
Mobile crusher – unloading ore	Unloading
Ore stockpile – unloading	Unloading
Power station R3D	Not estimated [a]
Surface HME	Miscellaneous vehicle
Waste rock stockpile – bulldozing	Bulldozing
Waste rock stockpile – unloading	Unloading
Waste rock stockpile – wind erosion	Wind erosion (active)
Underground Emission Sources (Emitted via Vents)	
Blasting – dust (ore/stope related)	Blasting – dust
Blasting – dust (waste rock/development related)	Blasting – dust
Blasting – explosive gases (ANFO)	Blasting – ANFO
Blasting – explosive gases (emulsion)	Blasting – emulsion
Diesel combustion - underground HME	Miscellaneous vehicle
Diesel combustion - underground light vehicles	Light goods vehicle
Drilling (ore/stope related)	Drilling
Drilling (waste rock/development related)	Drilling
Grading (waste rock/development related)	Grading
Hauling (unpaved road wheel generated dust)	Unpaved roads
Loading (ore/stope related)	Loading
Loading (waste rock/development related)	Loading
Radon emissions	Not estimated [a]

a – Emission rates were provided by ERA for these sources, therefore Pacific Environment have not estimated the emissions

12.2 EMISSION ESTIMATION METHODOLOGY

12.2.1 General Emission Estimation Methodology

In general, emissions are estimated from an activity using the following equation:

$$E_i = EF_i \times A \times \left(\frac{100 - CE_i}{100}\right)$$

where:

E_i	=	Emission rate for substance i	(kg/a)
EF_i	=	Uncontrolled emission factor for substance i	(kg/unit)
A	=	Activity rate	(unit/a)
CE_i	=	Overall control efficiency for substance i	(%)

Default emission factors for select activities are often available in literature, such as National Pollutant Inventory (NPI) Emission Estimation Manuals or the US EPA AP42. These emission factors have been determined based on a number of measurements taken during the activity at numerous locations. Some emission factors are dependent on site-specific inputs, such as material moisture content, and must be calculated prior to use in the above equation.

The emission factors used for each activity are described in Section 12.2.2 and the control factors, activity rates and site-specific emission factor inputs (if required) are described in Section 12.2.3.

Where $PM_{2.5}$ emission factors are unavailable (generally for non-combustion emissions), particle size ratios have been used to estimate $PM_{2.5}$ emissions based on PM_{10} emissions. Section 12.2.4 provides the particle size ratios used for the estimation of non-combustion $PM_{2.5}$ emissions. Similarly, if PM_{10} or TSP emission factors are unavailable, the particle size ratios described in Section 12.2.5 have been used to estimate emissions.

12.2.2 Emission Factors

Table 24 presents the emission factors used to estimate the emissions from each activity category.

Table 24 – Emission Factors Used in Assessment

Activity Category	Emission Factor					Unit	Reference
	TSP	PM_{10}	$PM_{2.5}$	NO_x	SO_2		
Batching operations	#	0.05	^	N/A	N/A	kg/t	Environment Australia (1999), Table 6
Blasting - ANFO	N/A	N/A	N/A	8	0.06	kg/t	DSEWPC (2012a), table 7
Blasting – dust	$\mathbf{0.00022 \times A^{1.5}}$ where: A = area blasted (m²)	$\mathbf{0.000114 \times A^{1.5}}$ where: A = area blasted (m²)	^	N/A	N/A	kg/blast	DSEWPC (2012b), Table 2
Blasting – emulsion	N/A	N/A	N/A	0.2	0	kg/t	DSEWPC (2012a), table 7
Bulldozing	$\mathbf{2.6 \times (s)^{1.2} / (M)^{1.3}}$ where: s = silt content (%) M = moisture content (%)	$\mathbf{0.34 \times (s)^{1.5} / (M)^{1.4}}$ where: s = silt content (%) M = moisture content (%)	^	N/A	N/A	kg/h	DSEWPC (2012b), Table 2
Drilling	0.59	0.31	^	N/A	N/A	kg/hole	DSEWPC (2012b), Table 2
Grading	$\mathbf{0.0034 \times S^{2.5}}$ where: S = mean vehicle speed (km/h)	$\mathbf{0.0034 \times S^{2}}$ where: S = mean vehicle speed (km/h)	^	N/A	N/A	kg/km	DSEWPC (2012b), Table 2
Light goods vehicle	#	0.0024	0.0023	0.0089	0.000017	kg/L	DEWHA (2008), Table 15
Loading	0.025	0.012	^	N/A	N/A	kg/t	DSEWPC (2012b), Table 2
Miscellaneous vehicle	#	0.0036	0.0033	0.045	0.000024	kg/L	DEWHA (2008), Table 35
Paved roads	$\mathbf{\frac{3.23}{1000} \times sL^{0.91} \times (W \times 1.1023)^{1.02}}$ where: sL = silt loading (g/m²) W = vehicle travel weighted average (t)	$\mathbf{EF_{TSP} \times \frac{0.62}{3.23}}$	$\mathbf{EF_{TSP} \times \frac{0.15}{3.23}}$	N/A	N/A	kg/km	US EPA (2011)

Primary crushing	0.2	0.02	^	N/A	N/A	kg/t	DSEWPC (2012b), Table 3
Screening	0.08	0.06	^	N/A	N/A	kg/t	DSEWPC (2012b), Table 3
Unloading	0.012	0.0043	^	N/A	N/A	kg/t	DSEWPC (2012b), Table 2
Unpaved roads	$\frac{\mathbf{0.4536}}{\mathbf{1.6093}} \times \mathbf{4.9} \times \left(\frac{s}{12}\right)^{0.7} \times \left(\frac{W \times 1.1023}{3}\right)^{0.45}$ where: $s = \text{silt content } (\%)$ $W = \text{vehicle travel weighted average } (t)$	$\frac{\mathbf{0.4536}}{\mathbf{1.6093}} \times \mathbf{1.5} \times \left(\frac{s}{12}\right)^{0.9} \times \left(\frac{W \times 1.1023}{3}\right)^{0.45}$ where: $s = \text{silt content } (\%)$ $W = \text{vehicle travel weighted average } (t)$	^	N/A	N/A	kg/km	DSEWPC (2012b), Table 2
Wind erosion (active)	0.4	0.2	^	N/A	N/A	kg/ha/h	DSEWPC (2012b), Table 2
Wind erosion (batching)	#	3.9	^	N/A	N/A	kg/ha/day	Environment Australia (1999), Table 6
Wind erosion (inactive)	0.85	*	^	N/A	N/A	t/ha	US EPA (1998)

= No TSP emission factor available. Emission factor derived using PM_{10} emission factor and particle size fraction described in Section 12.2.5.

^ = $PM_{2.5}$ emission factor available. Emission factor derived using $PM_{2.5}$ particle size fraction described in Section 12.2.4.

* = No PM_{10} emission factor available. Emission factor derived using TSP emission factor and particle size fraction described in Section 12.2.5.

N/A = Not applicable, i.e. substance not relevant to activity.

12.2.3 Input Data

Table 25, Table 26 and Table 27 describe the input data used to estimate emissions from each emission source/activity assessed for existing sources, incremental surface sources and incremental underground sources, respectively. For most sources, control efficiencies of intended control measures were sourced from Table 4 of the NPI EET Manual for Mining (DSEWPC, 2012). The exhaust control efficiencies for heavy mining equipment were provided by ERA, and are based on exhaust emission targets for the project. In all cases, input data and control measures will be finalised during final engineering design.

Table 25 – Input Data Used in Assessment (Existing Sources)

Emission Source	Control Efficiency	Input Data	Value	Unit	Notes
		Existing Emission Sources			
Diesel combustion - surface HME	0%	Fuel consumption	3,000,000	L	
Ore sorter (low moisture content ore)	99%	Amount or ore screened	0.4	Mt	Baghouse control
Ore stockpile – dumping ore	0%	Amount unloaded	0.4	Mt	N/A
Ore stockpile – loading ore	50%	Amount loaded	1	Mt	Water sprays control – watering down material before loading
Ore stockpile – wind erosion	30%	Area exposed	4	ha	Primary earthworks/rock armour control
Stockpile A – wind erosion	30%	Area exposed	30	ha	Primary earthworks/rock armour control
Stockpile B – loading ore	50%	Amount loaded	0.8	Mt	Water sprays control – watering down material before loading
Stockpile B – wind erosion (active area)	30%	Area exposed	4.8	ha	Primary earthworks/rock armour control
Stockpile B – wind erosion (inactive area)	30%	Area exposed	43.2	ha	Primary earthworks/rock armour control
Stockpile C – wind erosion	30%	Area exposed	8	ha	Primary earthworks/rock armour control
Wheel generated dust from paved roads throughout facility	0%	Total distance travelled	10,000	km	Based on 1 km each way per trip, total amount loaded and truck capacity
		Weight of vehicles	2	t	Assumption by Pacific Environment
		Silt loading	10	g/m²	Assumption by Pacific Environment
Wheel generated dust from unpaved roads (hauling ore from stockpile B to ore stockpile)	75%	Distance travelled each way per annum	10,860	km	Based on 2 km each way per trip, total amount loaded and truck capacity
		Weight of vehicle (empty)	102	t	Level 2 watering control
		Weight of vehicle (loaded)	249	t	
		General			
Ranger mine general information		Silt content of unpaved roads	10.5	%	
		Moisture content of ore, waste rock	4	%	
		Operating hours	8784	h	Assumed to operate continuously throughout the year

Table 26 – Input Data Used in Assessment (Surface Incremental Sources)

Emission Source	Control Efficiency	Input Data	Value	Unit	Notes
Backfill plant – aggregate unloading	0%	Amount unloaded	500,000	t	
Backfill plant – batching operations	99%	Amount of pastefill produced	1,000,000	t	Baghouse control or equivalent
Backfill plant – wind erosion of aggregate stockpile	0%	Area exposed	0.1	ha	
Hauling – aggregate from mobile crusher to backfill plant	75%	Distance travelled each way per annum	10,000	km	Based on 1 km each way per trip, total amount unloaded and truck capacity
Hauling – ore from portal to mobile crusher/ore sorter		Distance travelled each way per annum	6,400	km	Based on 0.8 km each way per trip, total amount unloaded and truck capacity
Hauling – ore from portal to ore stockpile		Distance travelled each way per annum	24,000	km	Based on 1 km each way per trip, total amount unloaded and truck capacity
Hauling – shotcrete from backfill plant to portal		Distance travelled each way per annum	720	km	Based on 0.2 km each way per trip and 3,600 trips
Hauling – waste rock from portal to waste rock stockpile		Distance travelled each way per annum	1,320	km	Based on 0.3 km each way per trip, total amount unloaded and truck capacity
Hauling – all surface hauling		Weight of vehicle (empty)	32.5	t	Level 2 watering control
		Weight of vehicle (loaded)	82.5	t	
Mobile crusher – crushing aggregate	50%	Amount of aggregate crushed	500,000	t	Low moisture content, water sprays on the crushing and screening unit or dust suppression on the feed material itself.
Mobile crusher – crushing ore	50%	Amount of ore crushed	400,000	t	Low moisture content, water sprays on the crushing and screening unit or dust suppression on the feed material itself.
Mobile crusher – loading aggregate	0%	Amount of aggregate loaded	1,000,000	t	
Mobile crusher – loading ore	0%	Amount of ore loaded	800,000	t	
Mobile crusher – unloading ore	0%	Amount of ore unloaded	400,000	t	
Ore stockpile – unloading	0%	Amount unloaded	1,600,000	t	
Surface HME	90% particulate 50% all substances	Fuel consumption	370,000	L	Emission control on exhaust fumes and additional control on diesel particulate.
Waste rock stockpile – bulldozing	0%	Total operating hours of bulldozers	500	h	
Waste rock stockpile – unloading	0%	Amount unloaded	220,000	t	
Waste rock stockpile – wind erosion	50%	Area exposed	2	ha	Water spraying control
Ranger mine general information		Silt content of unpaved roads	10.5	%	
		Moisture content of ore, waste rock	4	%	
		Operating hours	8784	h	Assumed to operate continuously throughout the year

Table 27 – Input Data Used in Assessment (Underground Incremental Sources – emitted via vents)

Emission Source	Control Efficiency	Input Data	Value	Unit	Notes
Blasting – dust (ore/stope related)	0%	Total number of blasts	300	blasts	
		Average stope blast area	100	m²	
Blasting – dust (waste rock/development related)	0%	Total number of blasts	2,500	blasts	
		Average development blast area	30	m²	
Blasting – explosive gases (ANFO)	0%	Amount of ANFO used	600	t	
Blasting – explosive gases (emulsion)	0%	Amount of Emulsion used	600	t	
Diesel combustion - underground HME	90% particulate 50% all substances	Fuel consumption	3,700,000	L	Emission control on exhaust fumes and additional control on diesel particulate.
Diesel combustion - underground light vehicles	0%	Fuel consumption	21,000	L	
Drilling (ore/stope related)	70%	Number of holes drilled	6,000	holes	Water spraying control
Drilling (waste rock/development related)	70%	Number of holes drilled	150,000	holes	Water spraying control
Grading (waste rock/development related)	90%	Distance travelled	4,3580	km	Wet conditions underground and level 2 watering when required.
		Average speed	5	km/h	
Hauling – ore from underground to portal	90%	Distance travelled each way per annum	128,000	km	Based on 4 km each way per trip, total amount unloaded and truck capacity
Hauling – waste rock from underground to portal		Distance travelled each way per annum	17,600	km	
Hauling – all underground hauling		Weight of vehicle (empty)	32.5	t	Wet conditions underground and level 2 watering when required.
		Weight of vehicle (loaded)	82.5	t	
Loading (ore/stope related)	50%	Amount loaded	1,600,000	t	Water sprays control – watering down material before loading
Loading (waste rock/development related)	50%	Amount loaded	220,000	t	
Underground wheel generated dust – shotcrete (agi truck)	90%	Distance travelled each way per annum	14,400	km	Based on 4 km each way per trip and 3,600 trips
		Weight of vehicle (empty)	5.5	t	Wet conditions underground and level 2 watering when required.
		Weight of vehicle (loaded)	15	t	
Underground wheel generated dust – IT vehicle		Total distance travelled per annum	11,680	km	
		Weight of vehicle	11	t	
Underground wheel generated dust – light vehicles		Total distance travelled per annum	175,930	km	
		Weight of vehicle	2	t	
Underground wheel generated dust – shotcreter		Total distance travelled per annum	11,680	km	
		Weight of vehicle	13.5	t	
		General			
Ranger mine general information		Silt content of unpaved roads	10.5	%	
		Moisture content of ore, waste rock	4	%	
		Operating hours	8784	h	Assumed to operate continuously throughout the year

12.2.4 Non-combustion $PM_{2.5}$ Emissions

$PM_{2.5}$ is a reportable NPI substance only for fuel combustion. As such, several NPI Manuals do not contain $PM_{2.5}$ emission factors. To determine these emissions, the activity emissions particle size ratios ($PM_{2.5}/PM_{10}$) were sourced from US EPA documents (Cowherd, Donaldson and Hegarty, 2006; US EPA 2001). The particle size ratios are primarily for the uncontrolled emissions except for wheel generated dust from unpaved roads. This fraction was taken from a study of controlled sources (in this case, unpaved roads controlled with water). The fraction used for blasting was provided by ERA, based on measurements taken during initial blasting for the mine expansion. The activities and associated particle size ratios used in this assessment are listed in Table 28. The use of this ratio is shown in the following equation:

$$\left(E_{PM_{2.5}}\right)_i = \left(\frac{PM_{2.5}}{PM_{10}}\right)_i \times \left(E_{PM_{10}}\right)_i$$

where:

$\left(E_{PM_{2.5}}\right)_i$ = Uncontrolled emission of $PM_{2.5}$ for activity *i* (kg/a)

$(PM_{2.5}/PM_{10})_i$ = Emissions particle size ratio for activity *i* (-)

$\left(E_{PM_{10}}\right)_i$ = Uncontrolled emission of PM_{10} for activity *i* (kg/a)

Table 28 – $PM_{2.5}$ Particle Size Ratios for Industrial Activities

Activity	$PM_{2.5}$:PM_{10}	Source
Wind erosion	0.15	Cowherd, Donaldson and Hegarty (2006)
Blasting	0.74	ERA
Wheel generated dust (unpaved)	0.374	US EPA (2001)
All other activities	0.15	Cowherd, Donaldson and Hegarty (2006)[a]

a – All other sources assumed to have the same particle size ratios as aggregate handling.

As $PM_{2.5}$ particle size ratios of controlled sources are not readily available and neither are control factors specific to $PM_{2.5}$, the $PM_{2.5}$ emissions calculated using the equation above may give results higher than the calculated controlled PM_{10} emissions. Given that $PM_{2.5}$ is a subset of PM_{10}, the emissions must be less than or equal to the PM_{10} emissions. In the absence of appropriate control factors for $PM_{2.5}$, if the uncontrolled $PM_{2.5}$ emission calculated is greater than the controlled PM_{10} emission, the $PM_{2.5}$ emission is conservatively assumed to be equal to the controlled PM_{10} emission.

12.2.5 PM_{10}/TSP size fractions

In some cases, emission factors for both TSP and PM_{10} are not provided in the EET source documents. However, the unavailable emission factor can be estimated in a similar fashion to the $PM_{2.5}$ calculation in Section 12.2.4 using the PM_{10}/TSP particle size fractions in Table 29.

Table 29 – PM_{10}/TSP Particle Size Ratios for Industrial Activities

Activity	PM_{10}:TSP	Source
Wind erosion	0.50	US EPA (2006)
All other sources [a]	0.51	US EPA (1996)

a – All other sources assumed to have the same particle size ratios as mechanically generated emissions from the handling and processing of aggregate and unprocessed ores.

For combustion sources, the TSP emissions have been assumed equal to the PM_{10} emissions.

13 APPENDIX B – EMISSION SOURCE CHARACTERISTICS

13.1 EXISTING EMISSIONS

The parameters modelled for each existing emission source are presented in Table 30 to Table 33.

Table 30 – Existing Point Source Characteristics

Source ID	X-coordinate (km)	Y-coordinate (km)	Stack Height (m)	Stack Diameter (m)	Temperature (˚C)	Exit Velocity (m/s)
Diesel Fired Boiler	274.304	8597.075	12	0.61	187	14.0
Waste Heat Boiler1	274.316	8597.044	10	0.50	200	22.3
Waste Heat Boiler2	274.317	8597.046	10	0.50	200	22.3
Waste Heat Boiler3	274.317	8597.043	10	0.50	200	22.3
Waste Heat Boiler4	274.321	8597.046	10	0.50	200	22.3
Waste Heat Boiler5	274.326	8597.024	10	0.50	200	22.3
Waste Heat Boiler6	274.331	8597.027	10	0.50	200	22.3
Waste Heat Boiler7	274.327	8597.023	10	0.50	200	22.3
Waste Heat Boiler8	274.332	8597.026	10	0.50	200	22.3
Primary Crusher Scrubber	274.110	8596.850	10	0.80	Ambient	30.2
Coarse Ore Reclaim Scrubber	274.289	8596.955	6	0.40	Ambient	11.9
Fine Crusher Scrubber1	274.289	8596.955	21	0.80	Ambient	25.7
Fine Crusher Scrubber 2	274.289	8596.955	30	0.80	Ambient	31.4
Power Station	274.410	8597.074	40	2.00	450	11.6

Table 31 – Existing Area Source Dimensions

Source ID	Effective Height (m)	Initial Sigma Z (m)	Area (m²)
Ore Stockpile	10.00	1.25	17,000
Stockpile A	10.00	1.25	183,000
Stockpile B	10.00	1.25	422,000
Stockpile C	10.00	1.25	101,000
HR15	0.88	1.25	5,000
HR16	0.88	1.25	4,400
HR17	0.88	1.25	4,200
HR18	0.88	1.25	3,200
HR19	0.88	1.25	3,100
HR20	0.88	1.25	3,300
HR21	0.88	1.25	6,100
HR22	0.88	1.25	6,600
HR23	0.88	1.25	3,200
HR24	0.88	1.25	5,800
Paved Roads	0.88	1.25	197,000

Table 32 – Existing Area Source Coordinates

Source ID	X-coordinates (km)				Y-coordinates (km)			
Ore Stockpile	273.862	273.857	274.023	274.011	8596.754	8596.856	8596.865	8596.750
Stockpile A	272.862	272.962	273.341	273.375	8597.912	8598.354	8598.349	8597.968
Stockpile B	272.519	272.935	273.417	273.078	8597.018	8597.586	8597.448	8596.715
Stockpile C	273.187	272.752	272.755	273.106	8595.942	8596.157	8596.254	8596.371
HR15	273.022	272.844	272.858	273.038	8597.030	8597.113	8597.134	8597.052
HR16	272.858	273.021	273.037	272.876	8597.134	8597.263	8597.248	8597.122
HR17	273.021	273.189	273.190	273.037	8597.263	8597.390	8597.366	8597.248
HR18	273.190	273.189	273.328	273.329	8597.366	8597.390	8597.408	8597.386
HR19	273.329	273.328	273.481	273.483	8597.386	8597.408	8597.426	8597.408
HR20	273.483	273.481	273.645	273.651	8597.408	8597.426	8597.452	8597.432
HR21	273.631	273.627	273.651	273.657	8597.186	8597.428	8597.432	8597.185
HR22	273.635	273.631	273.657	273.665	8596.949	8597.186	8597.185	8596.949
HR23	273.643	273.635	273.665	273.671	8596.838	8596.949	8596.949	8596.837
HR24	273.671	273.670	273.902	273.904	8596.837	8596.862	8596.873	8596.848
Paved Roads	274.470	274.276	274.767	274.919	8596.760	8597.122	8597.332	8597.036

Table 33 – Existing Volume Source Characteristics

Source ID	X-coordinate (km)	Y-coordinate (km)	Effective Height (m)	Initial Sigma Y (m)	Initial Sigma Z (m)
Loading at Ore Stockpile	273.916	8596.781	1.75	2.25	0.88
Dumping at Primary Crusher	274.109	8596.842	2.37	9.25	1.18
Loading at Stockpile B	272.995	8597.162	1.75	2.25	0.88
Ore Sorter	274.080	8596.910	8.00	10.00	4.00

13.2 INCREMENTAL EMISSIONS

The parameters modelled for each incremental emission source are presented in Table 34 to Table 37.

Table 34 – Incremental Emissions Point Source Characteristics

Source ID	X-coordinate (km)	Y-coordinate (km)	Stack Height (m)	Stack Diameter (m)	Temperature (˚C)	Exit Velocity (m/s)
Exhaust 1	274.200	8598.242	10	3.30	28	18.7
Exhaust 2	274.452	8597.977	10	3.35	28	18.7
Exhaust 3	274.679	8597.726	10	3.35	28	18.7
Exhaust 4	274.717	8597.374	10	2.48	28	18.7
Power Station	274.522	8597.096	25	1.35	466	19.1

Table 35 – Incremental Area Source Characteristics

Source ID	Effective Height (m)	Initial Sigma Z (m)	Area (m²)
HR1	0.88	1.25	700
HR2	0.88	1.25	900
HR3	0.88	1.25	1,400
HR4	0.88	1.25	2,000
HR5	0.88	1.25	2,400
HR6	0.88	1.25	2,000
HR7	0.88	1.25	1,900
HR8	0.88	1.25	2,400
HR9	0.88	1.25	1,800
HR10	0.88	1.25	1,600
HR11	0.88	1.25	1,600
HR12	0.88	1.25	2,500
HR13	0.88	1.25	1,500
HR14	0.88	1.25	1,000
Waste Rock Stockpile	10	1.00	4,900

Table 36 – Incremental Area Source Coordinates

Source ID	X-coordinates (km)				Y-coordinates (km)			
HR1	274.405	274.415	274.479	274.478	8597.335	8597.341	8597.307	8597.298
HR2	274.337	274.331	274.404	274.411	8597.286	8597.295	8597.336	8597.329
HR3	274.339	274.349	274.417	274.405	8597.285	8597.290	8597.191	8597.186
HR4	274.329	274.316	274.416	274.426	8597.124	8597.139	8597.190	8597.177
HR5	274.229	274.215	274.317	274.328	8597.063	8597.080	8597.138	8597.122
HR6	274.128	274.119	274.215	274.228	8597.015	8597.028	8597.079	8597.063
HR7	274.028	274.026	274.119	274.129	8596.961	8596.980	8597.027	8597.013
HR8	273.900	273.900	274.026	274.027	8596.947	8596.965	8596.979	8596.959
HR9	273.899	273.879	273.896	273.915	8596.861	8596.964	8596.965	8596.861
HR10	274.470	274.412	274.428	274.482	8597.303	8597.396	8597.402	8597.308
HR11	274.343	274.335	274.413	274.427	8597.382	8597.405	8597.415	8597.403
HR12	274.234	274.236	274.334	274.342	8597.362	8597.390	8597.402	8597.382
HR13	274.412	274.457	274.470	274.428	8597.416	8597.485	8597.474	8597.404
HR14	274.012	274.028	274.042	274.029	8596.906	8596.961	8596.967	8596.898
Waste Rock Stockpile	274.148	274.159	274.238	274.228	8597.369	8597.423	8597.416	8597.350

Table 37 – Incremental Volume Source Characteristics

Source ID	X-coordinate (km)	Y-coordinate (km)	Effective Height (m)	Initial Sigma Y (m)	Initial Sigma Z (m)
Backfill Plant Process Operations	274.545	8597.695	1.50	1.25	0.75
Backfill Plant Wind Erosion – Aggregate Stockpiles	274.550	8597.700	5.00	2.50	2.50
Trucks Dumping at Ore Stockpile	273.921	8596.791	2.95	2.56	1.48
Trucks Dumping at Waste Rock Stockpile	274.228	8597.399	2.95	2.56	1.48
Bulldozing at Waste Rock Stockpile	274.175	8597.380	1.44	2.83	0.72
Crushing and Screening Plant	273.274	8596.163	2.00	3.75	1.00

14 APPENDIX C – DISPERSION MODELLING RESULTS - COUNTOURS

14.1 EXISTING EMISSIONS

The predicted existing ground-level concentrations throughout the study area are presented in Figure 11 to Figure 22.

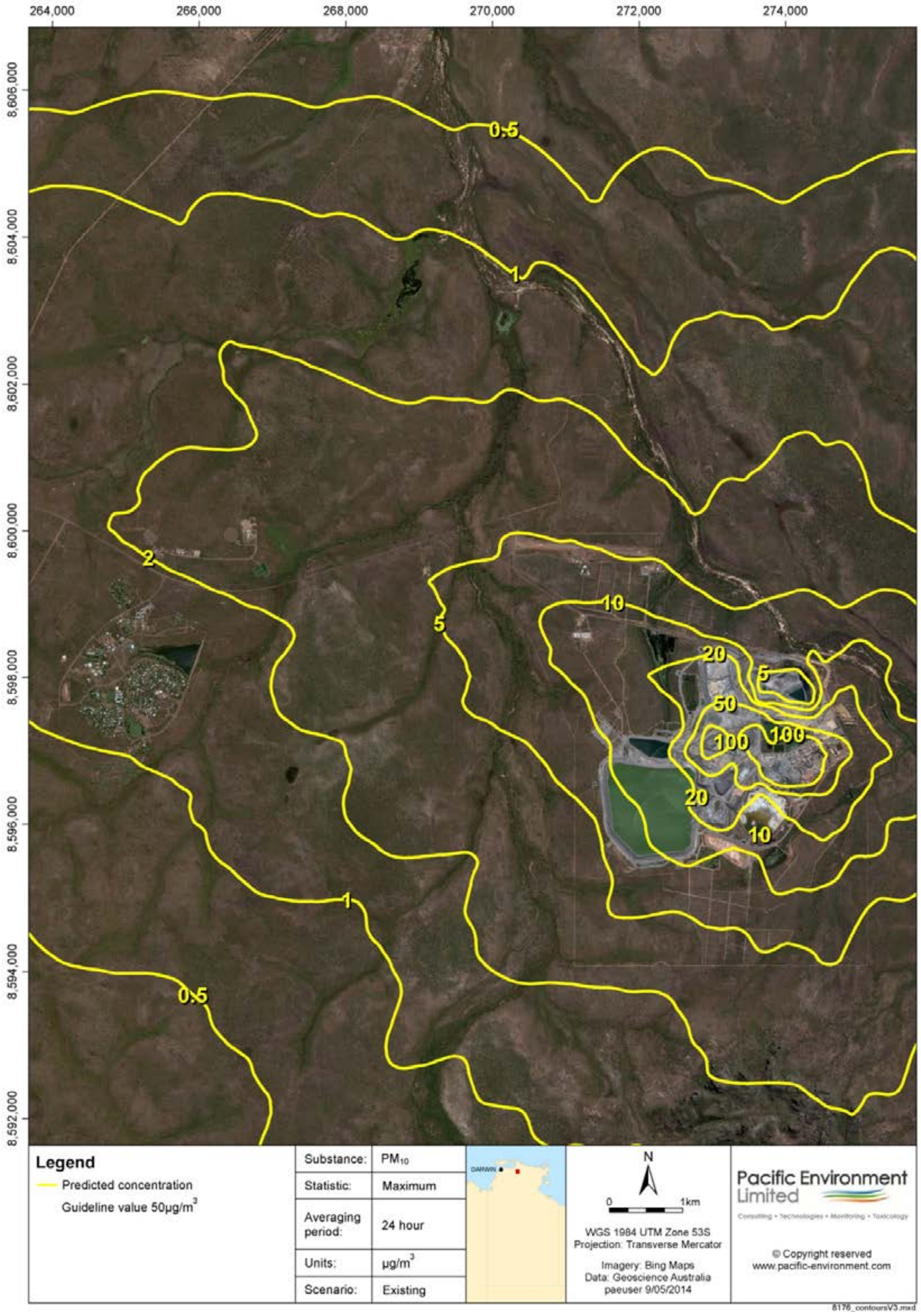


Figure 11 – Existing Maximum PM_{10} Concentrations (24-hr Average)

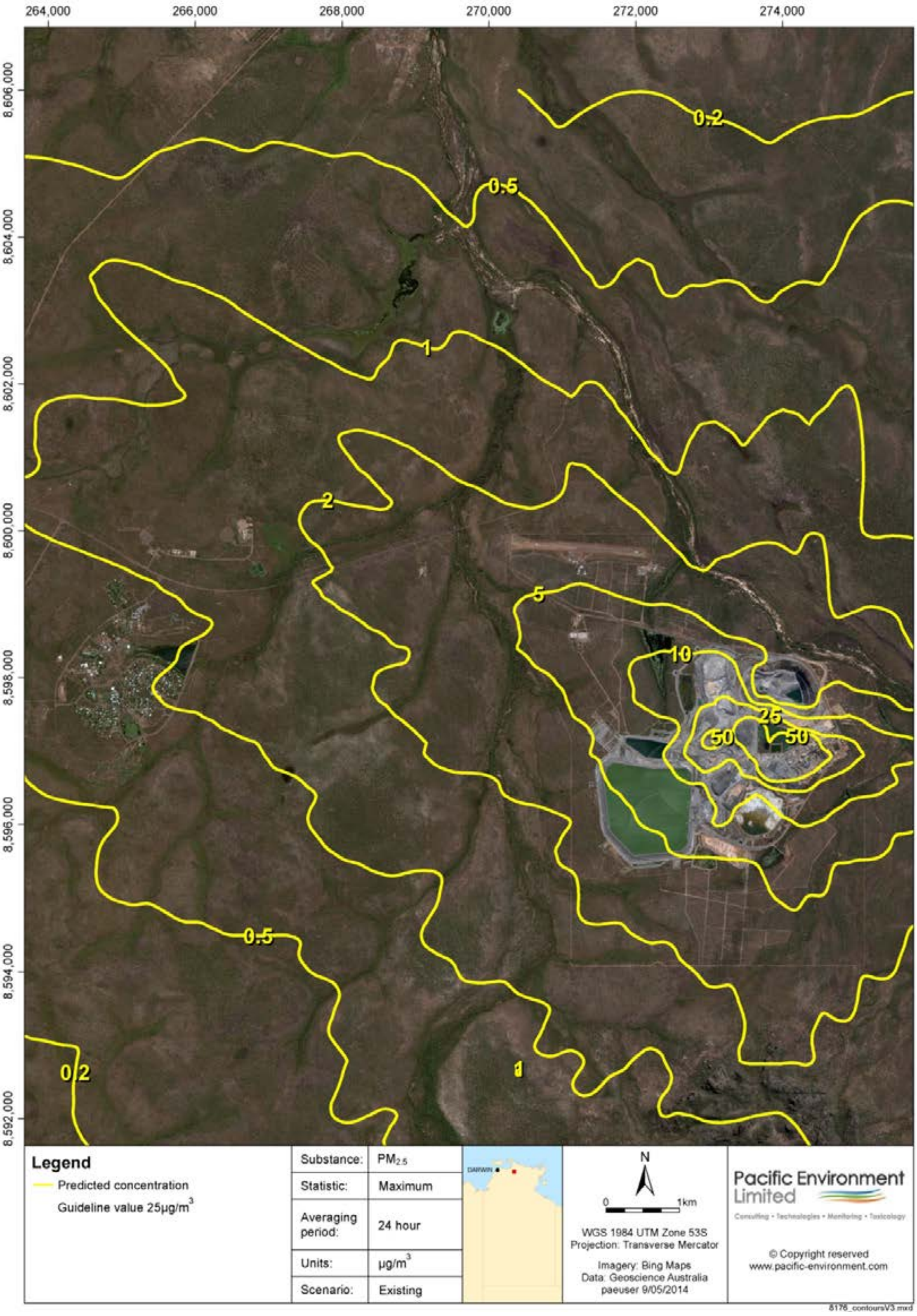


Figure 12 - Existing Maximum $PM_{2.5}$ Concentrations (24-hr Average)

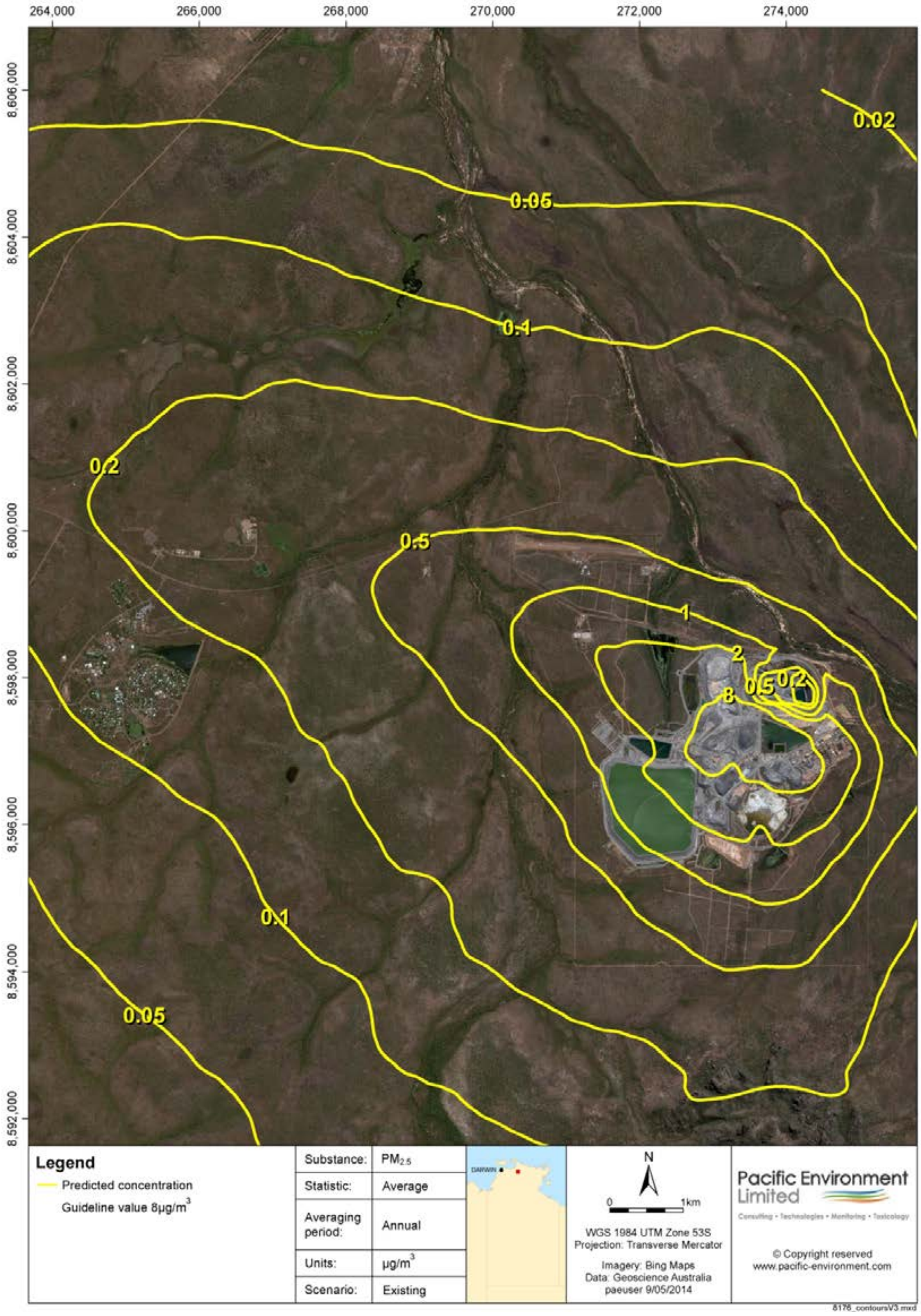


Figure 13 - Existing $PM_{2.5}$ Concentrations (Annual Average)

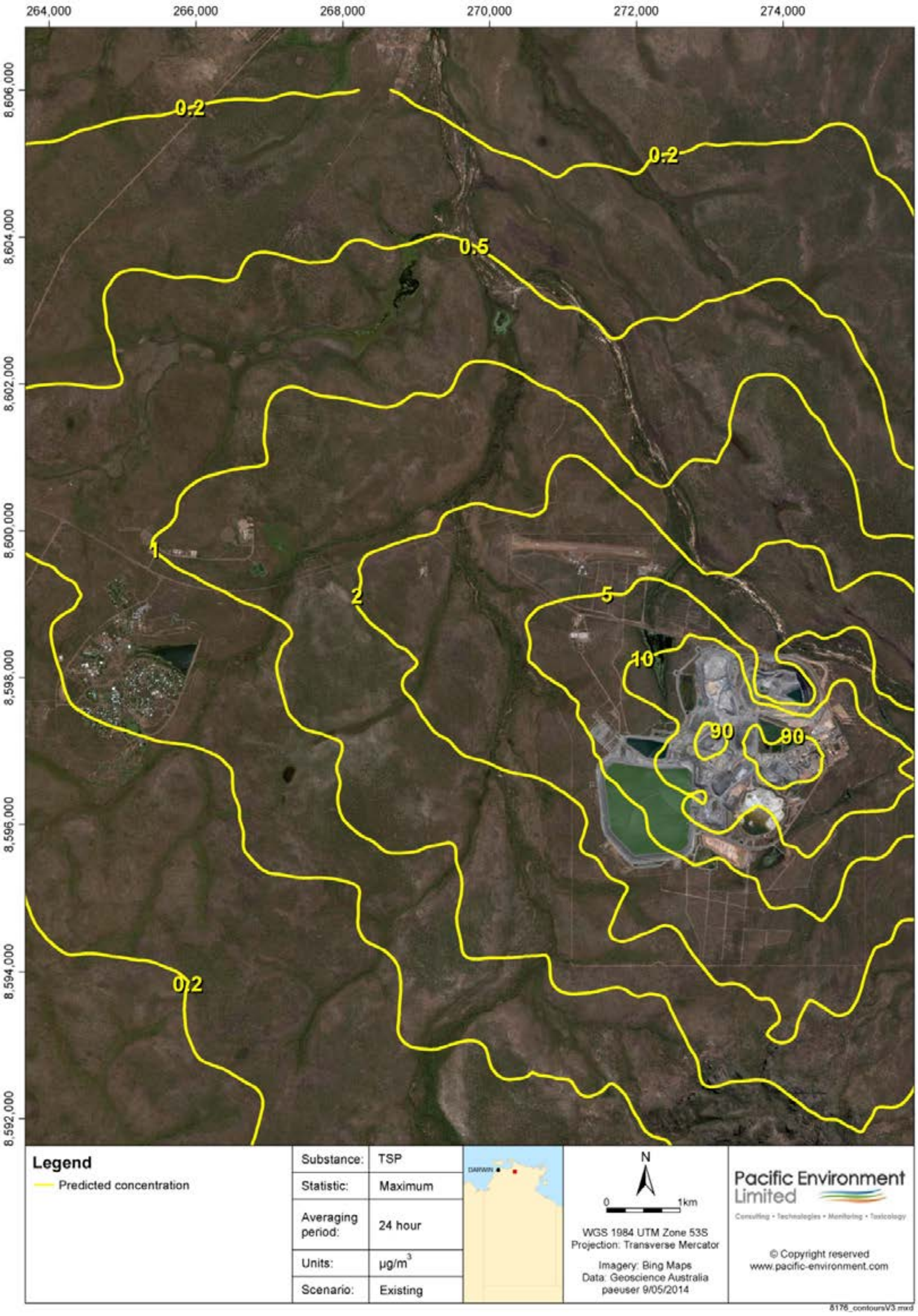


Figure 14 - Existing Maximum TSP Concentrations (24-hr Average)

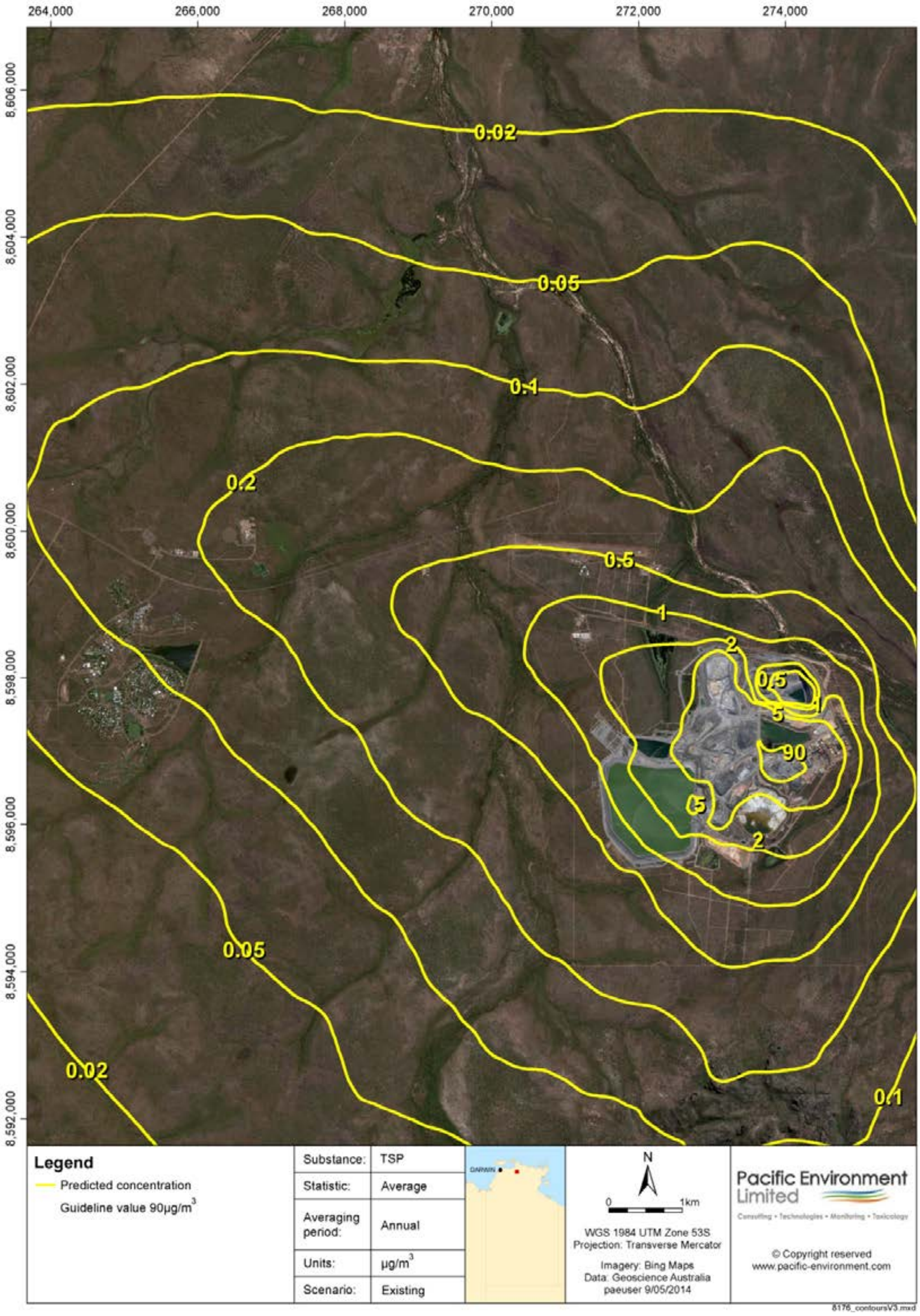


Figure 15 - Existing TSP Concentrations (Annual Average)

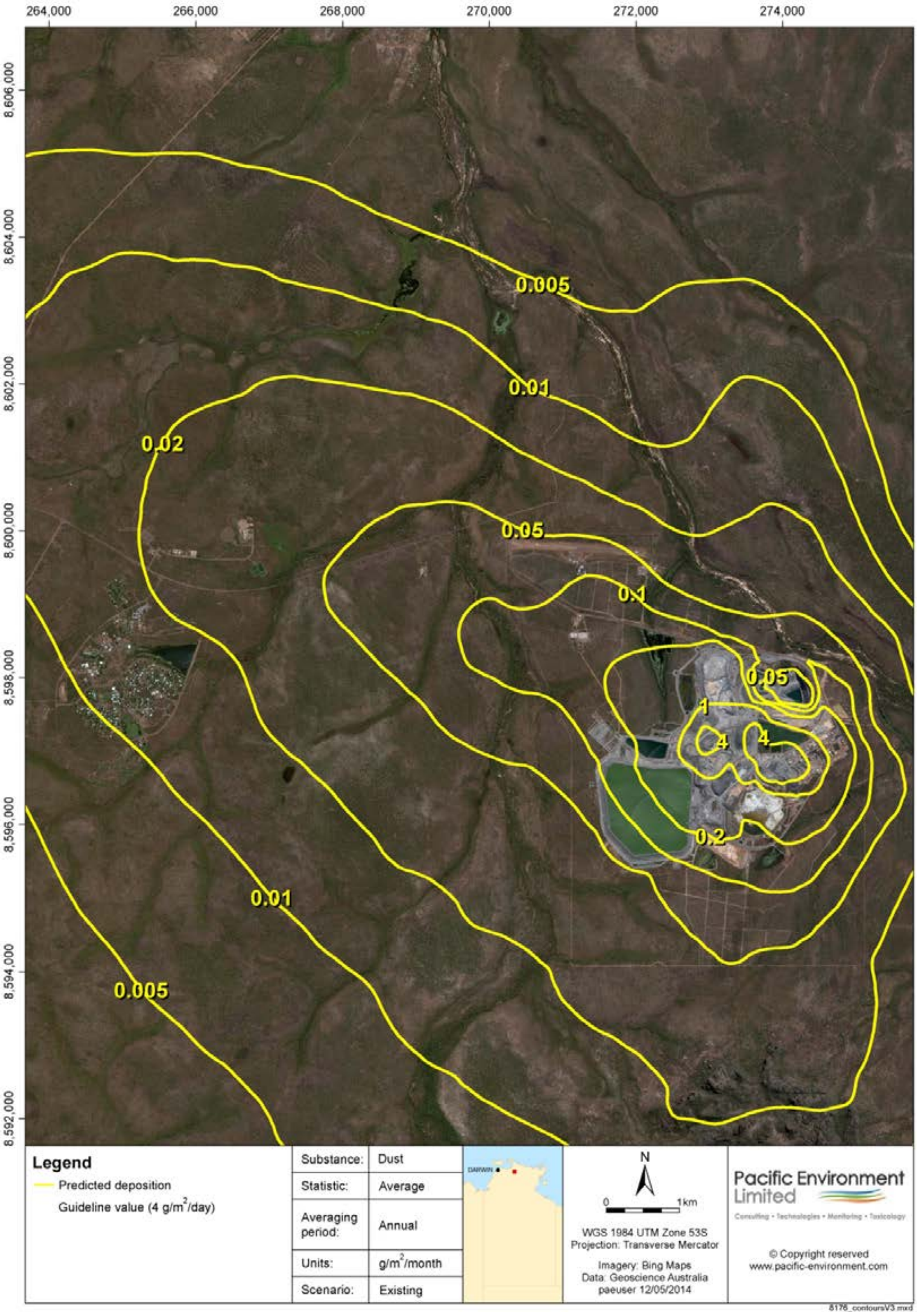


Figure 16 - Existing Dust Deposition Rate (Annual Average)

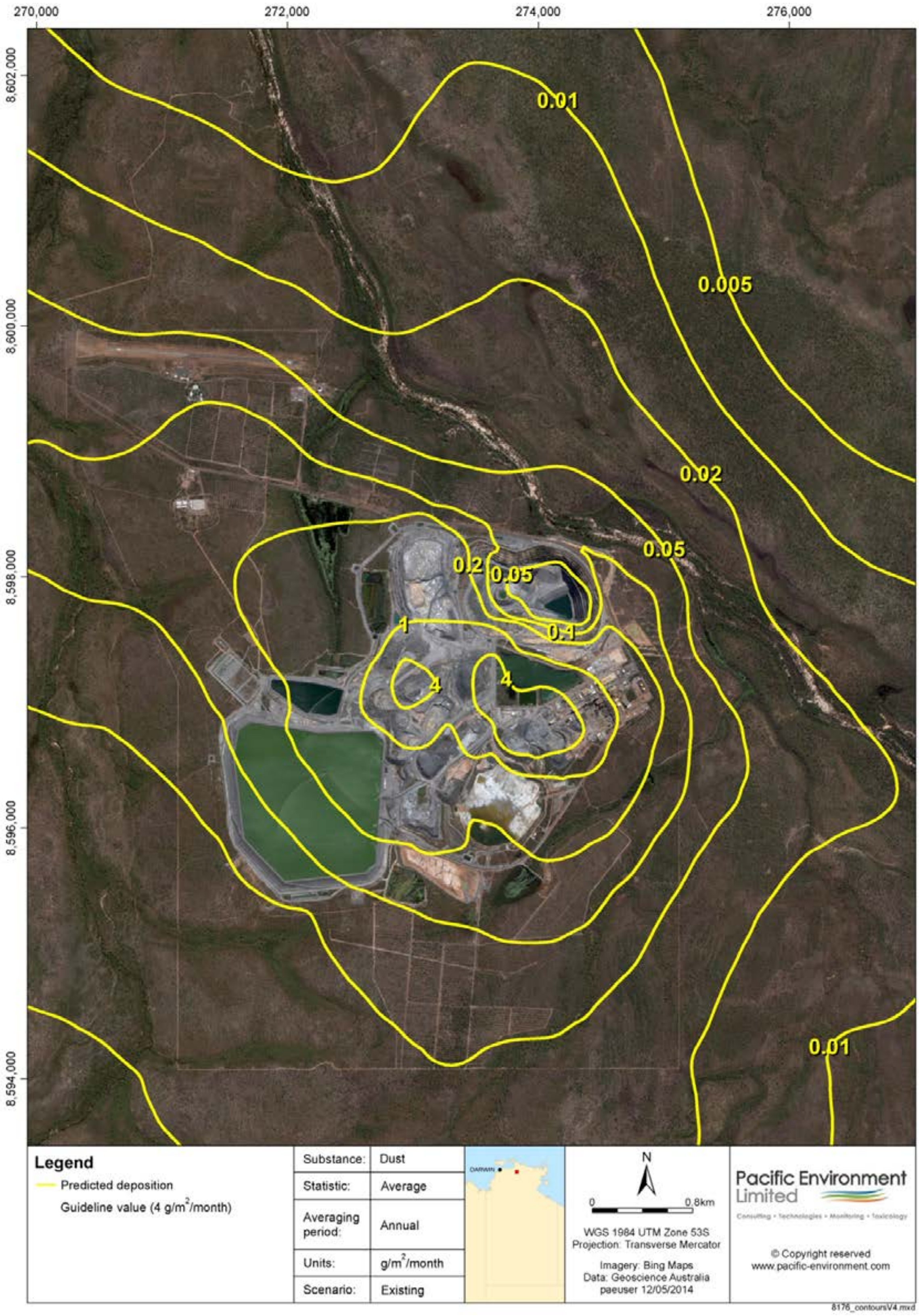


Figure 17 - Existing Dust Deposition Rate (Annual Average) – Mine Footprint

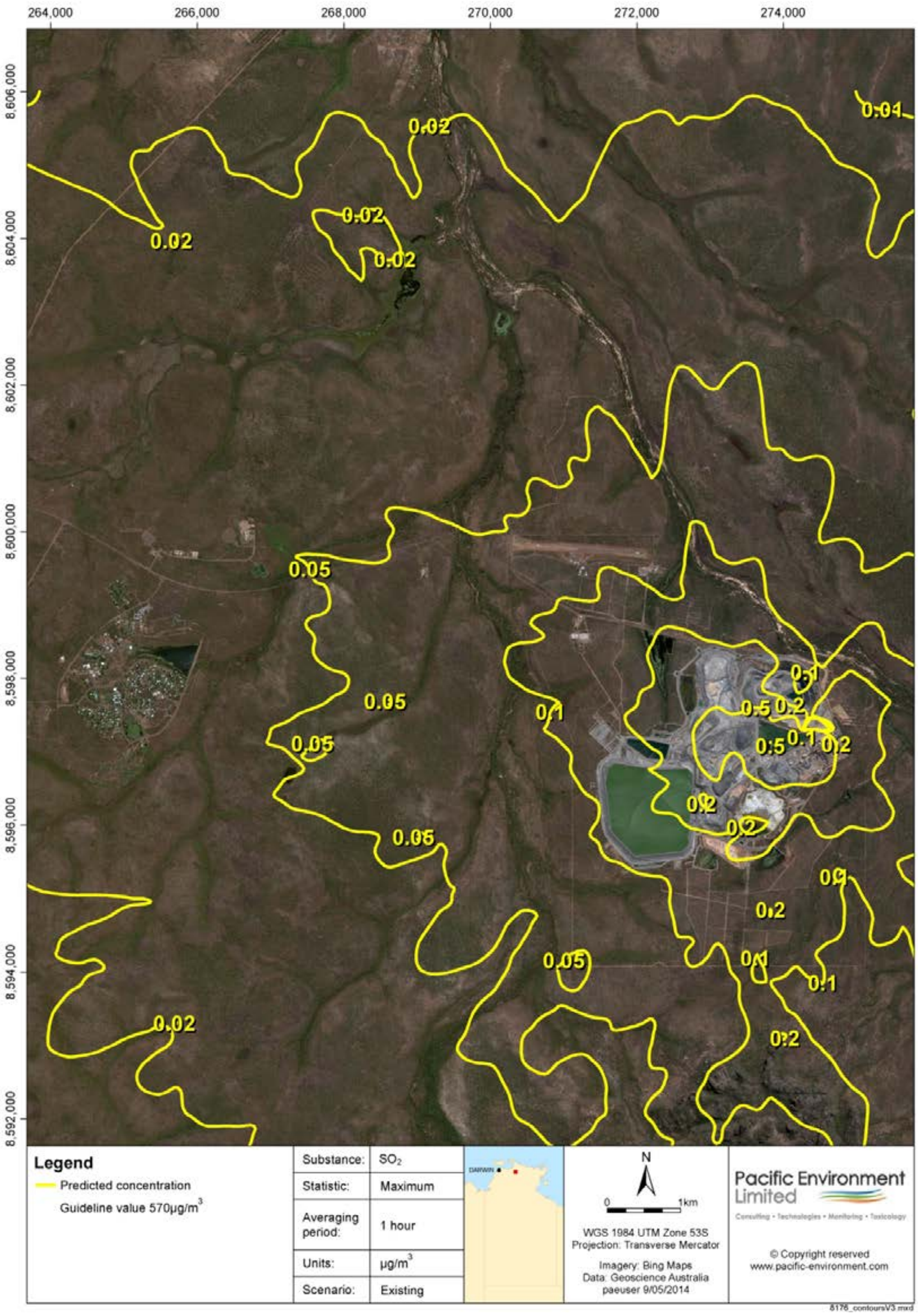


Figure 18 – Existing Maximum SO_2 Concentrations (1-hr Average)

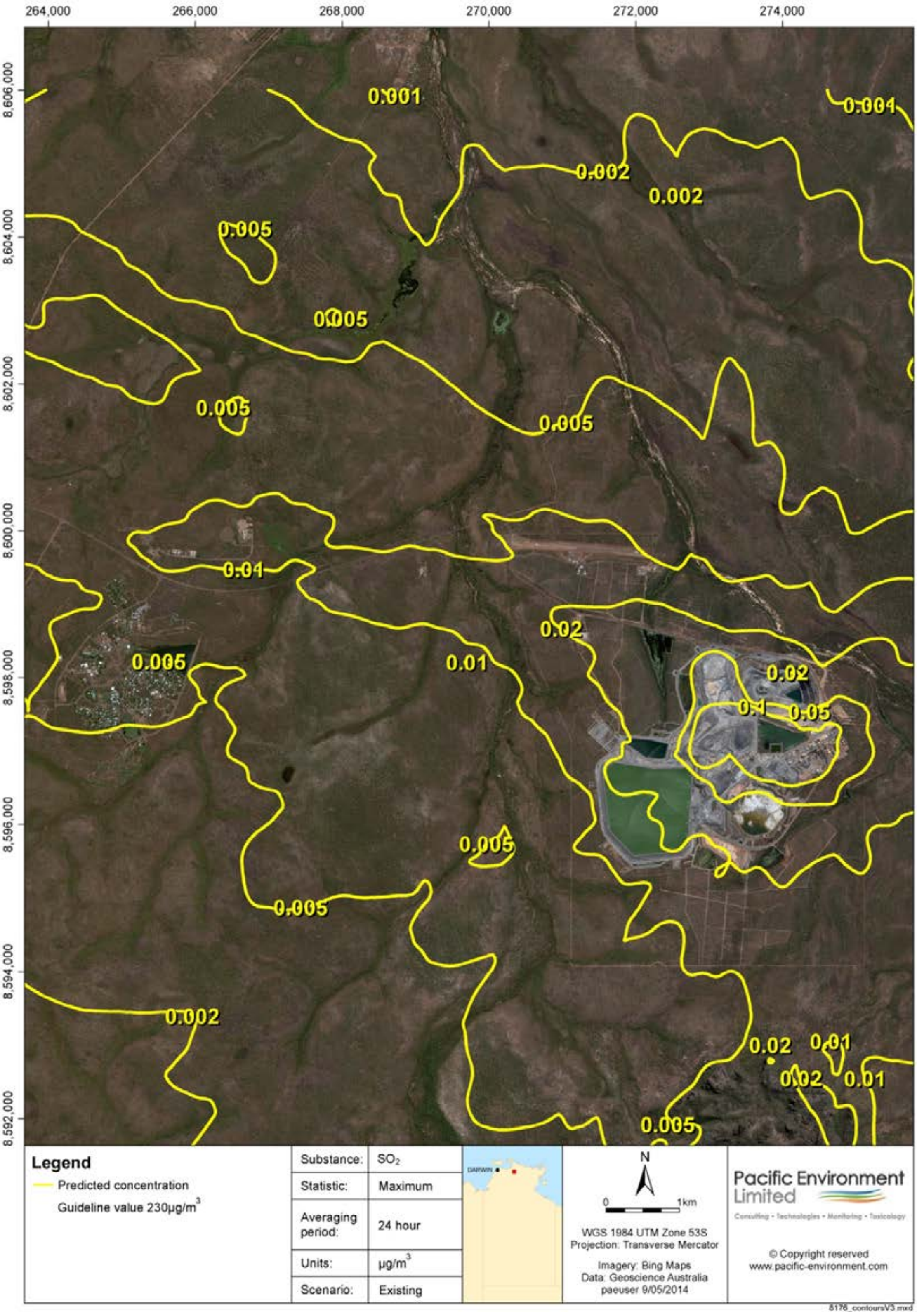


Figure 19 - Existing Maximum SO_2 Concentrations (24-hr Average)

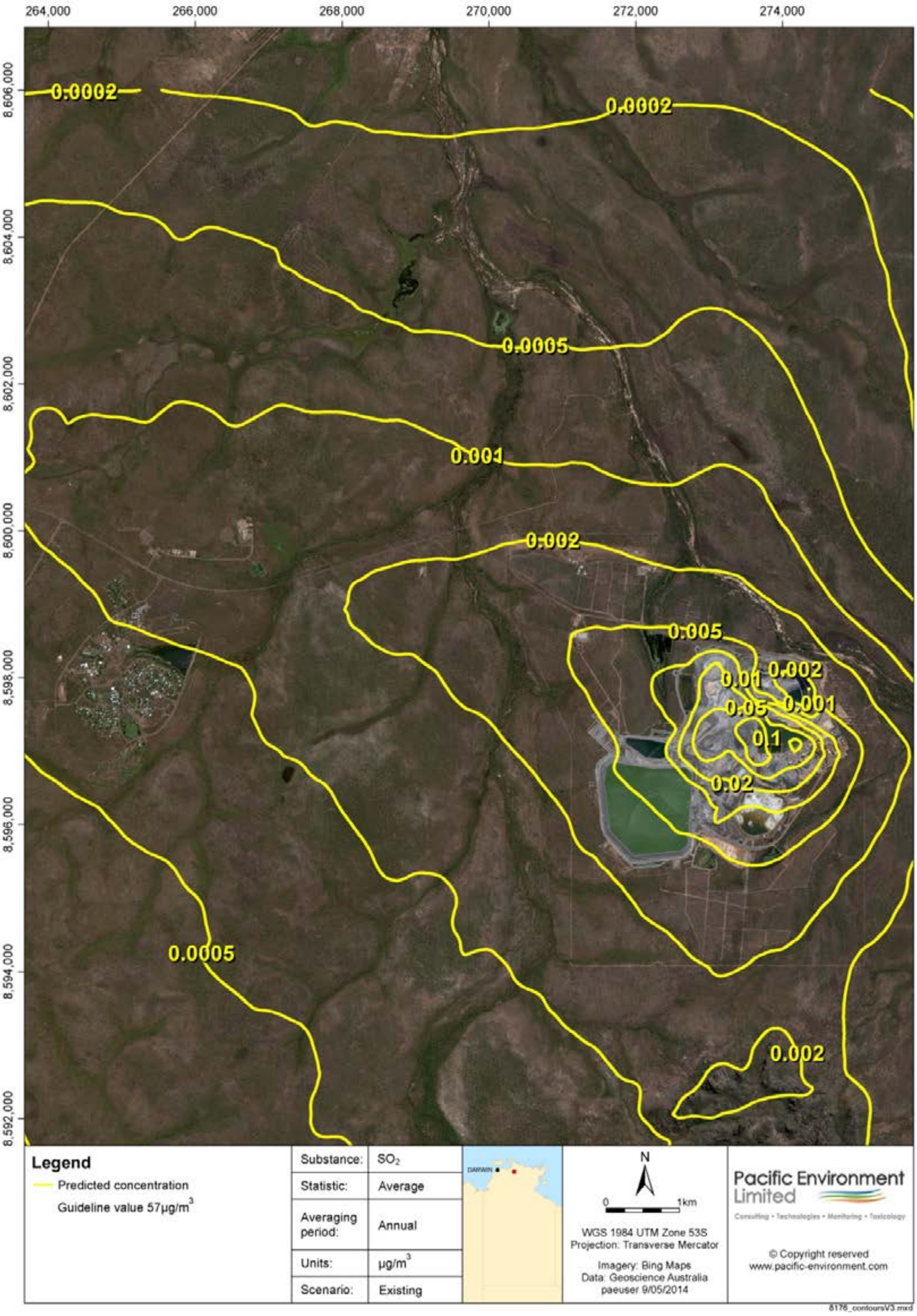


Figure 20 - Existing SO_2 Concentrations (Annual Average)

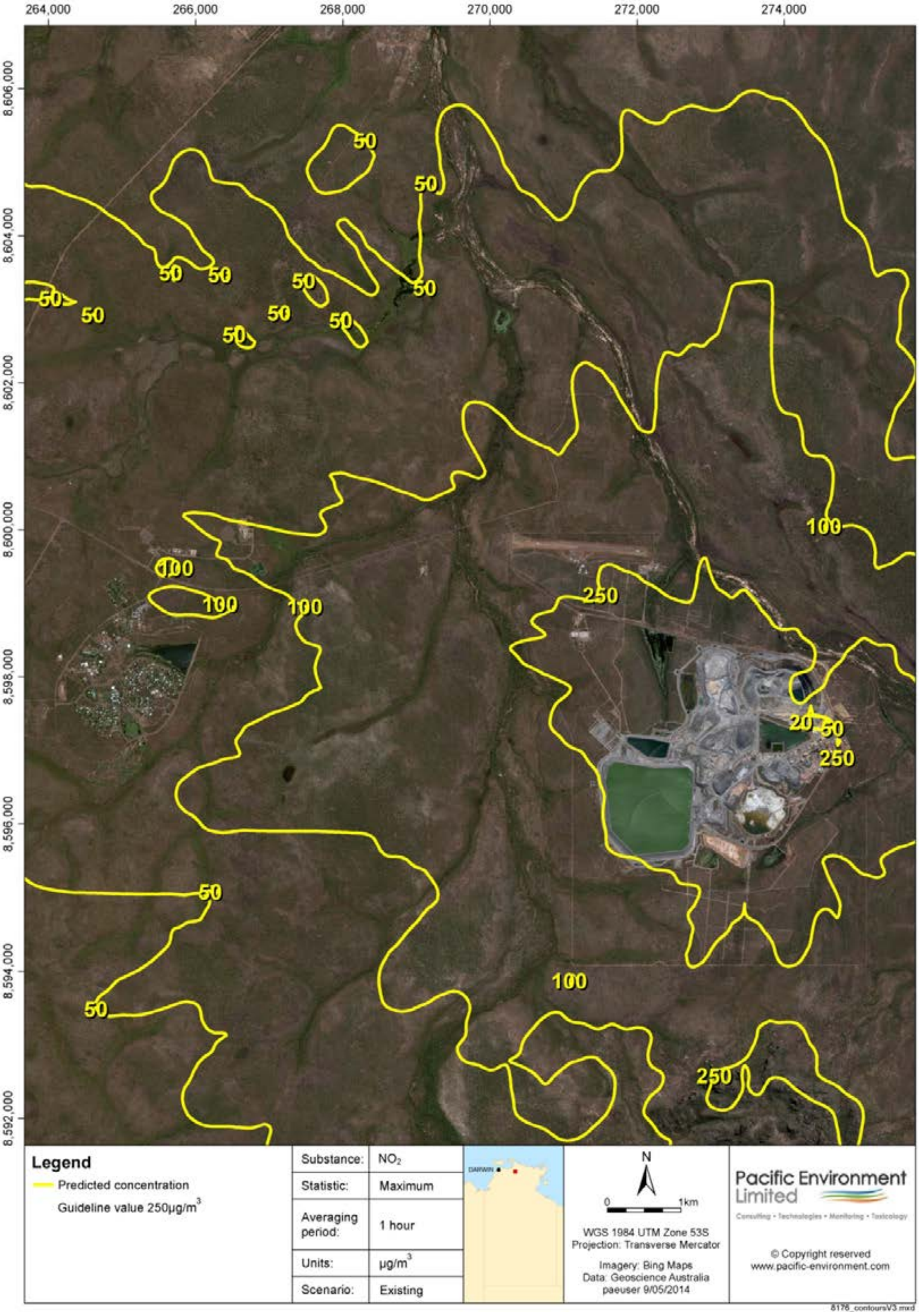


Figure 21 – Existing Maximum NO_2 Concentrations (1-hr Average)

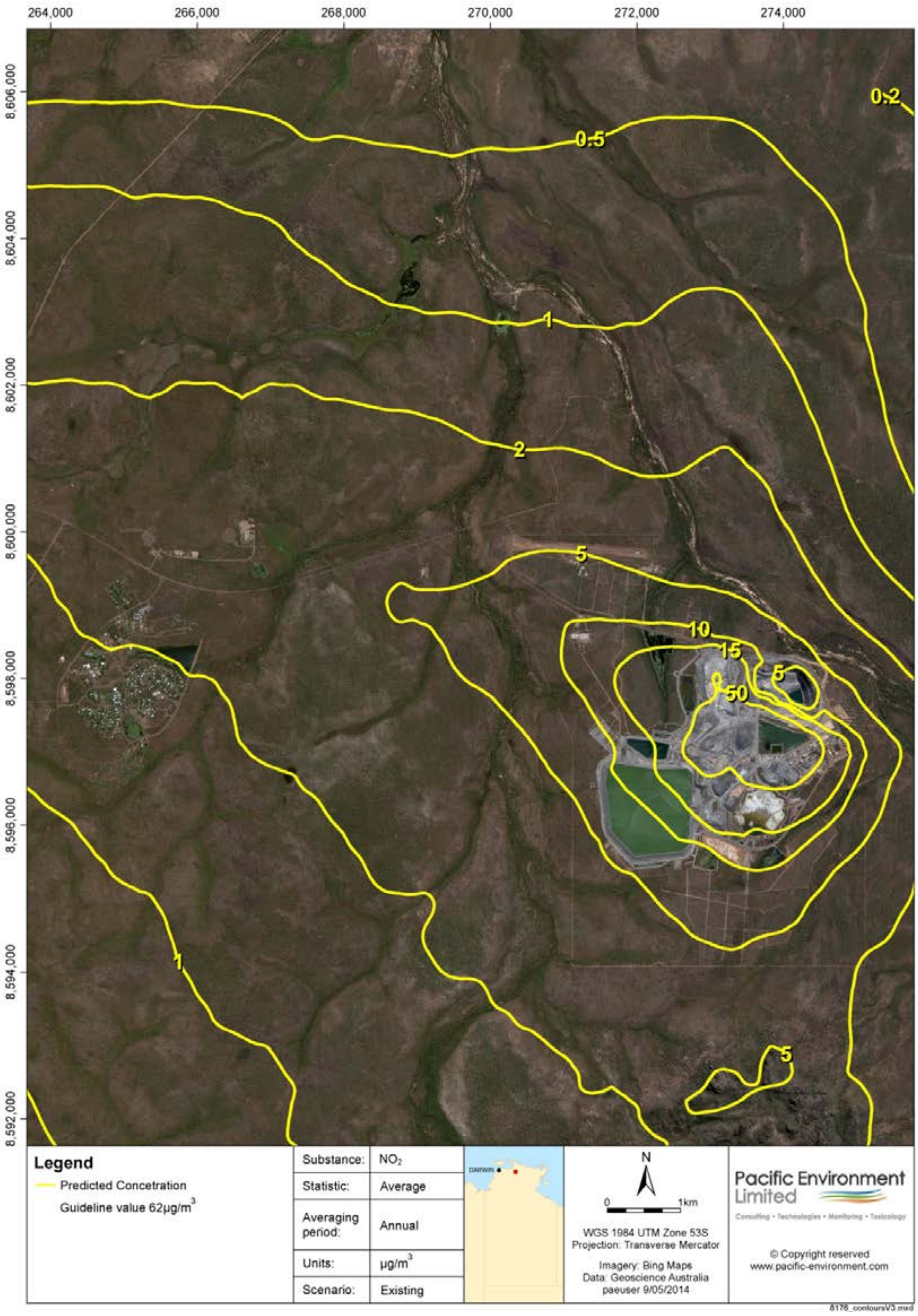


Figure 22 - Existing NO_2 Concentrations (Annual Average)

14.2 INCREMENTAL EMISSIONS

The predicted Project ground-level concentrations throughout the study area are presented in Figure 23 to Figure 38.

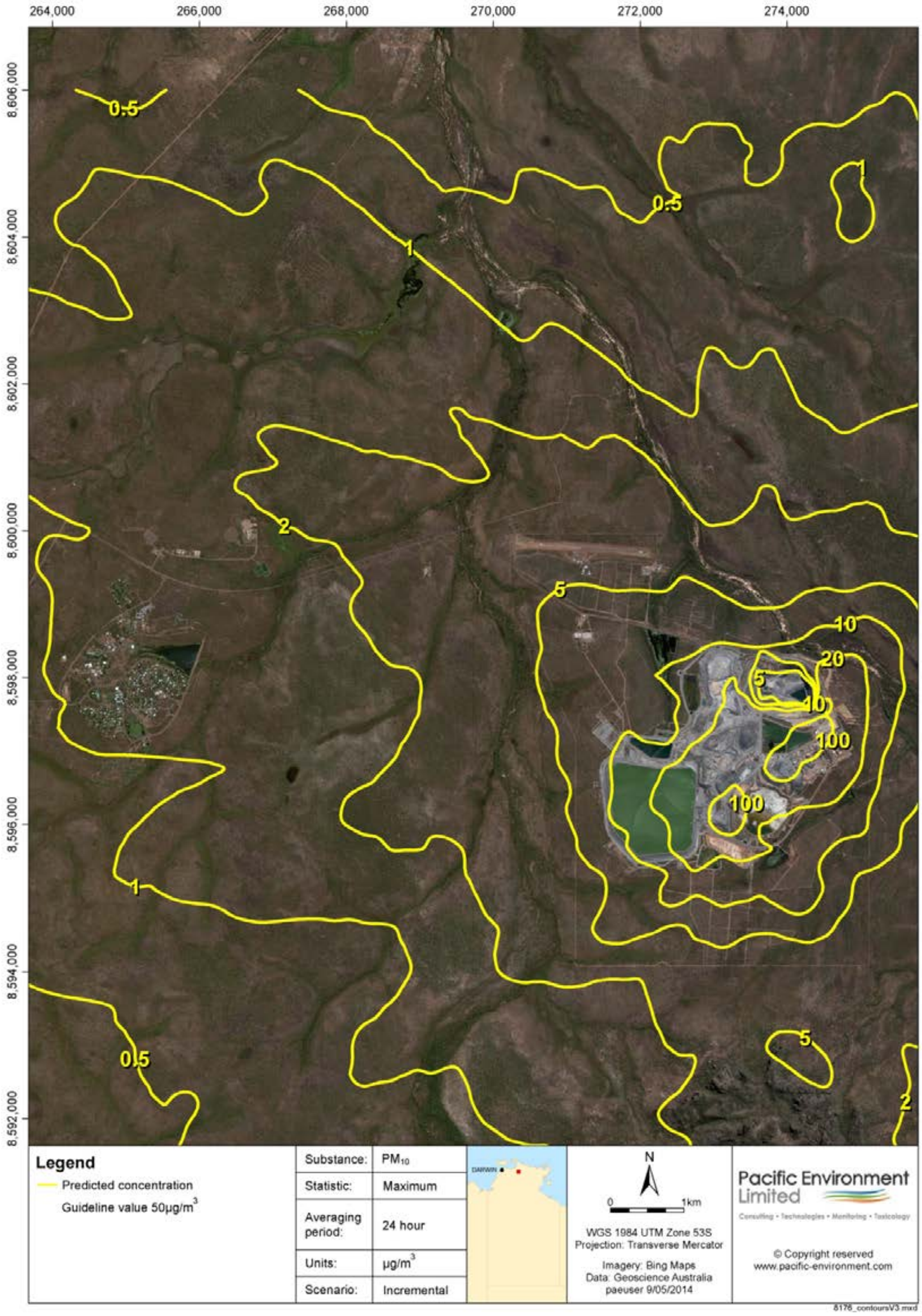


Figure 23 - Incremental Maximum PM_{10} Concentrations (24-hr Average)

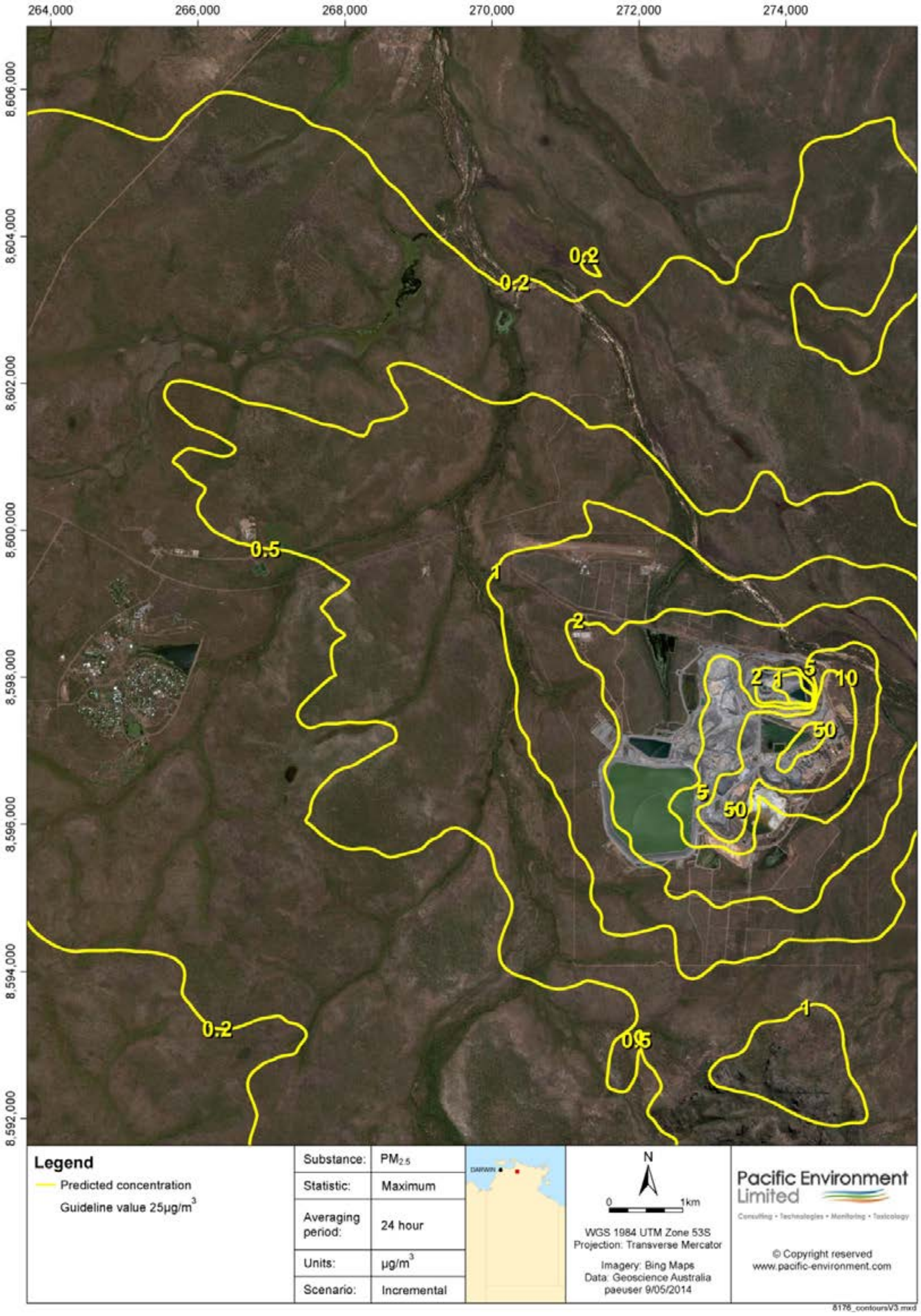


Figure 24 - Incremental Maximum $PM_{2.5}$ Concentrations (24-hr Average)

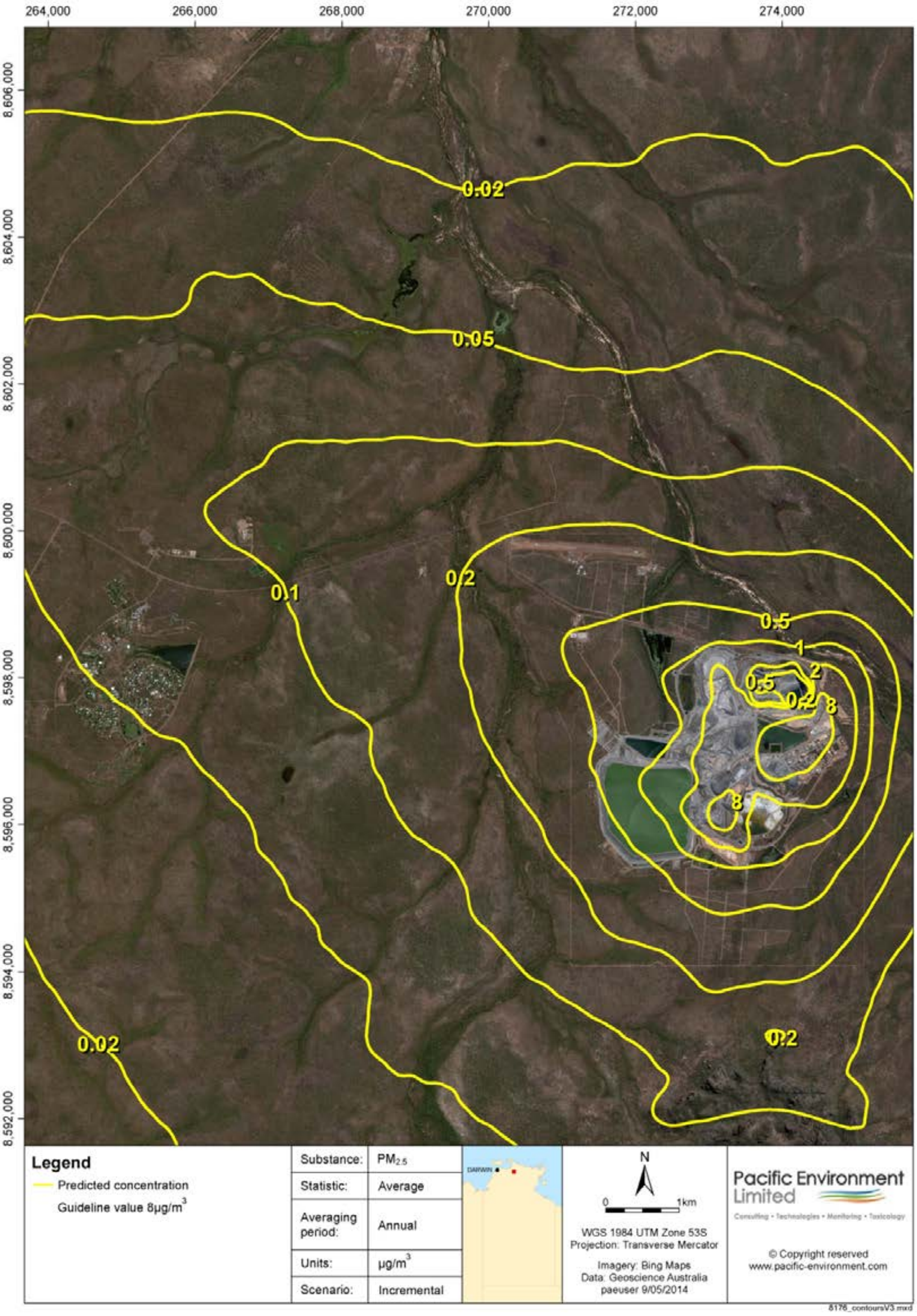


Figure 25 - Incremental $PM_{2.5}$ Concentrations (Annual Average)

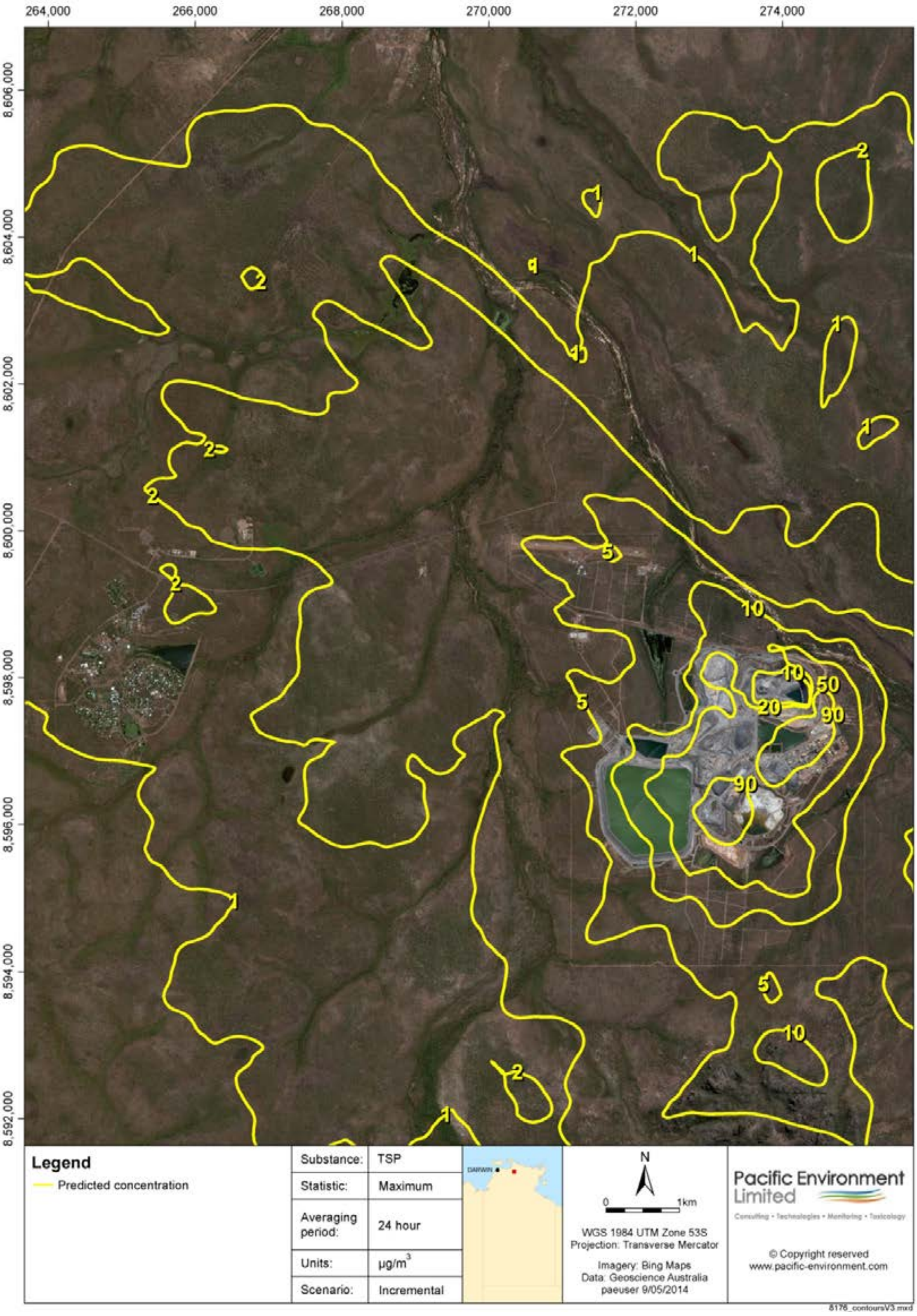


Figure 26 - Incremental Maximum TSP Concentrations (24-hr Average)

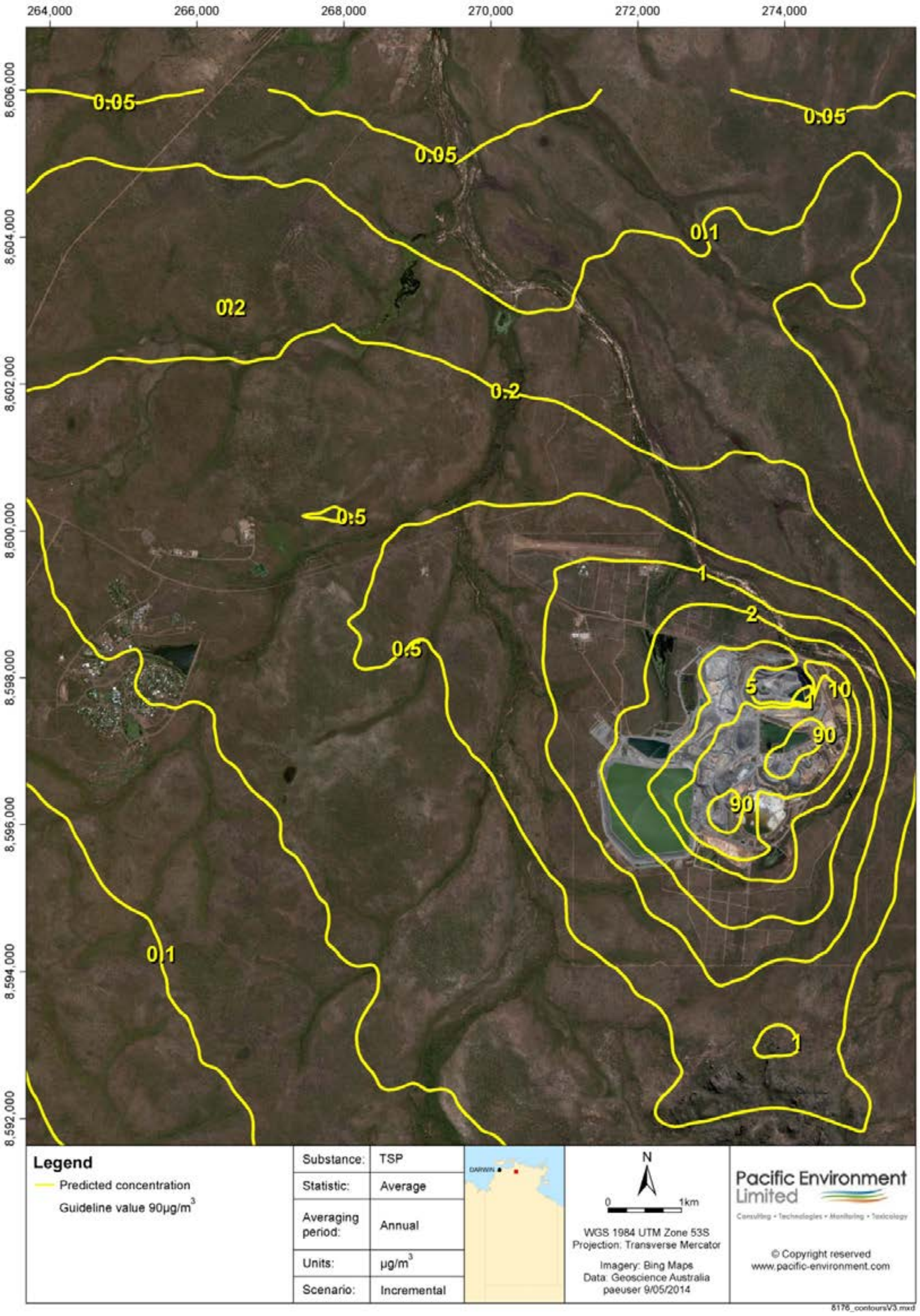


Figure 27 - Incremental TSP Concentrations (Annual Average)

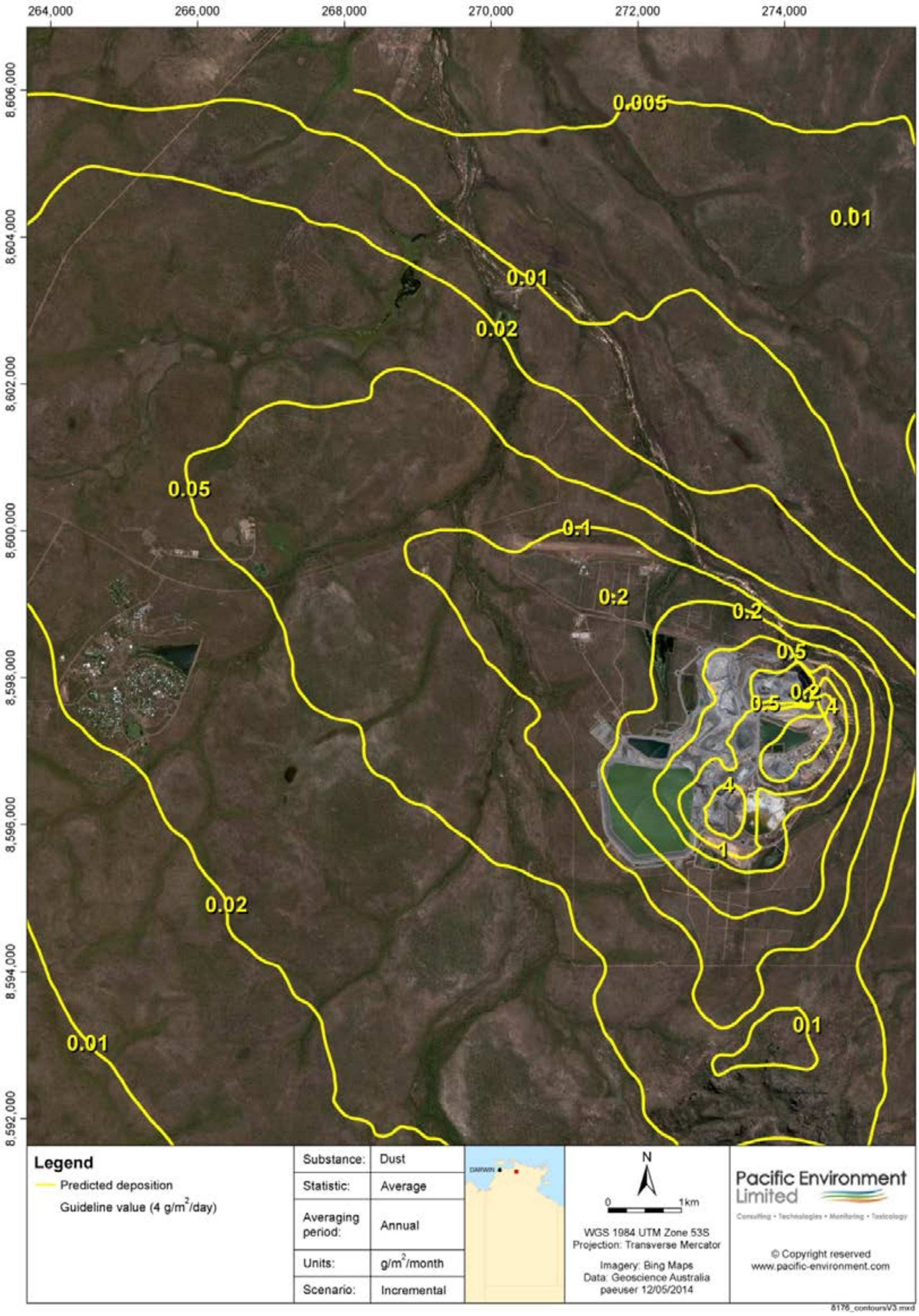


Figure 28 - Incremental Dust Deposition Rate (Annual Average)

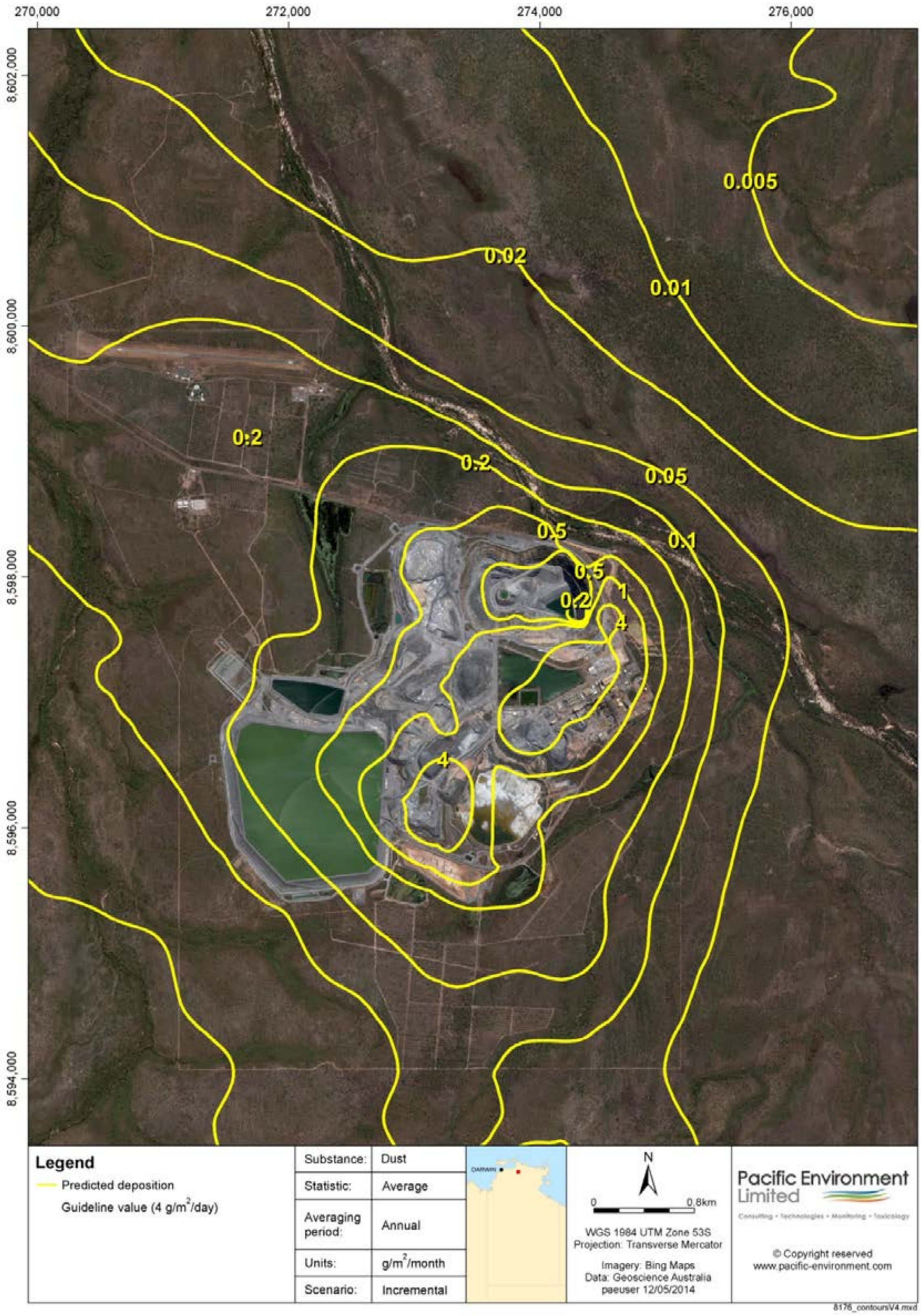


Figure 29 - Incremental Dust Deposition Rate (Annual Average) – Mine Footprint

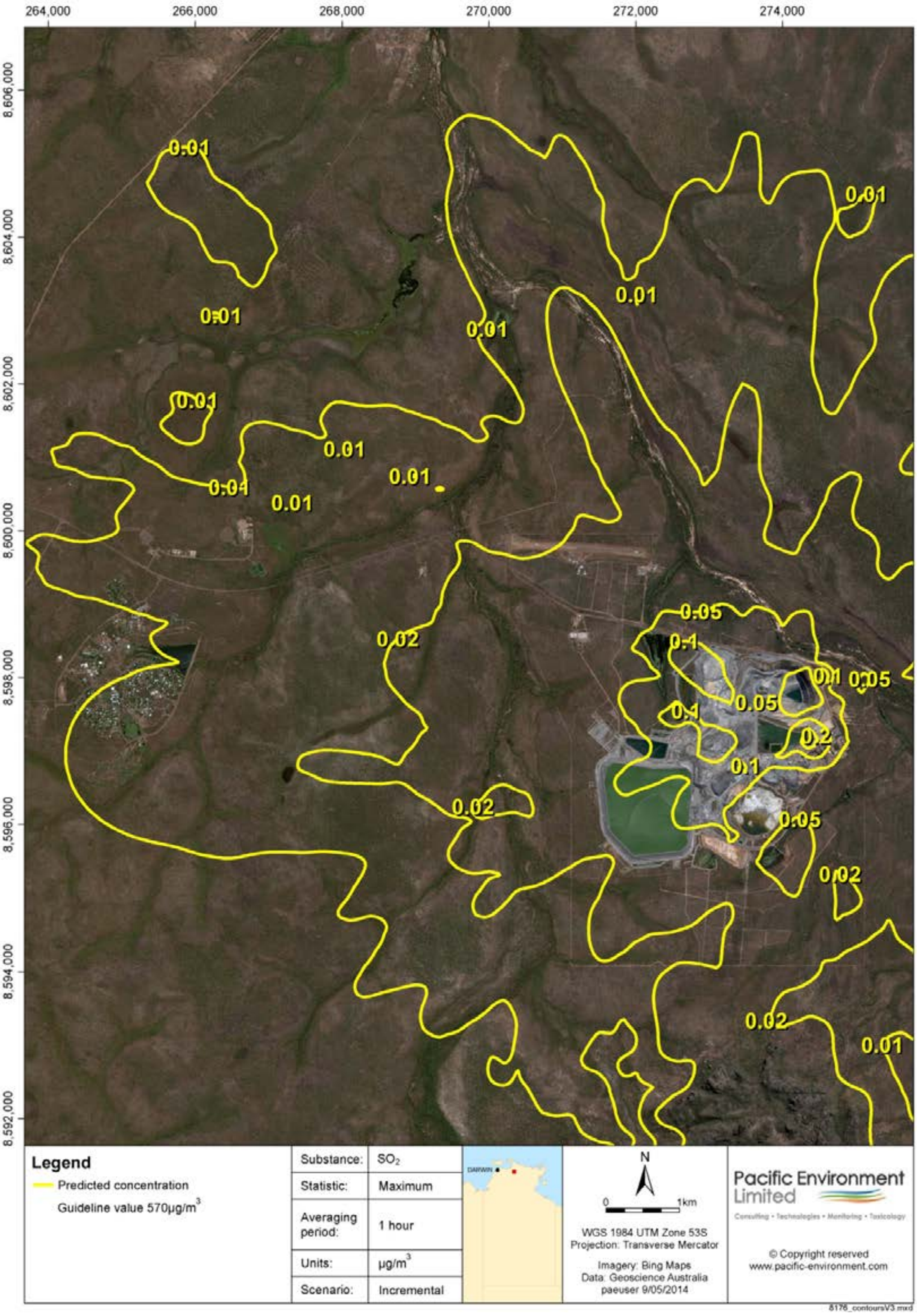


Figure 30 - Incremental Maximum SO_2 Concentrations (1-hr Average)

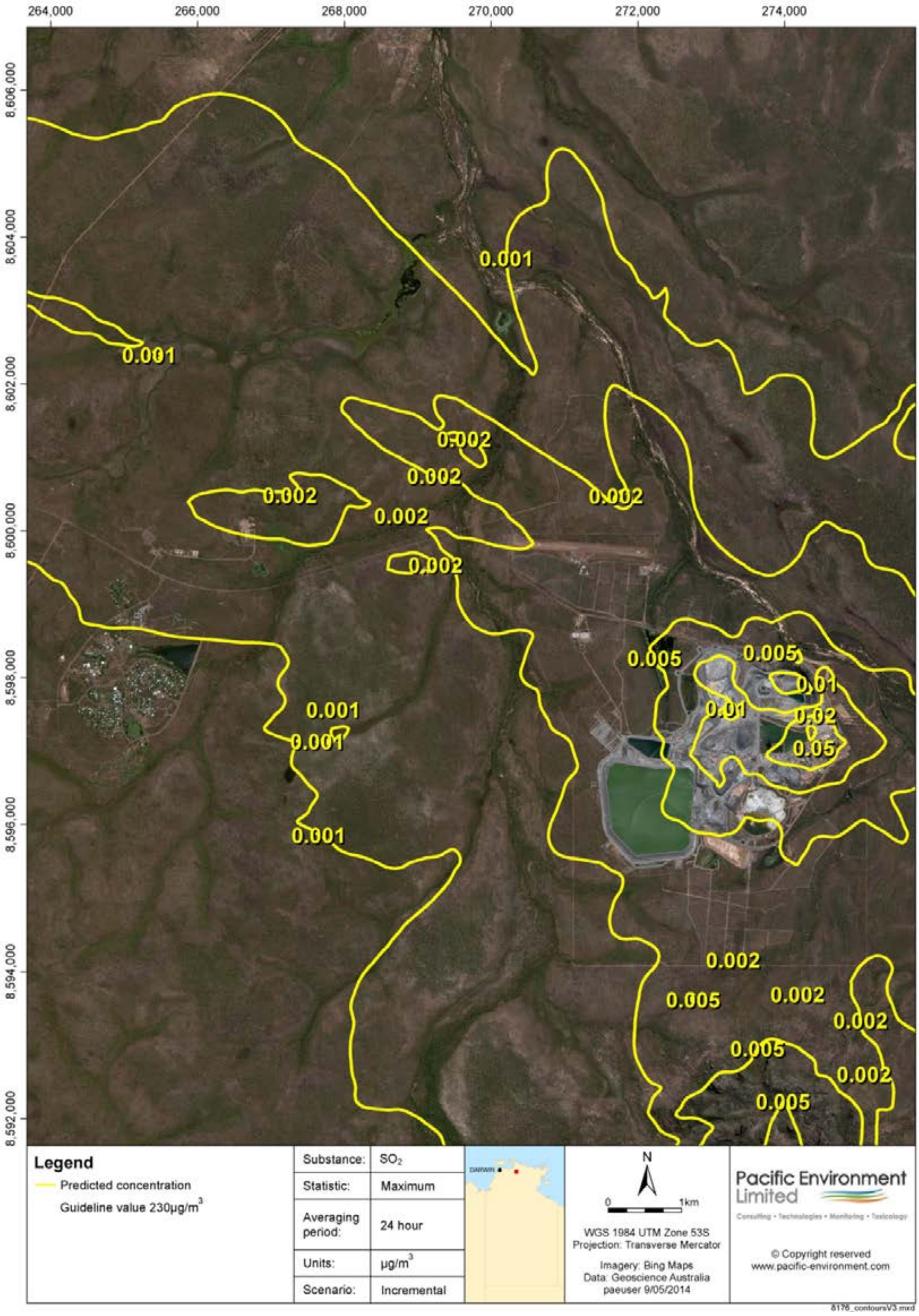


Figure 31 - Incremental Maximum SO_2 Concentrations (24-hr Average)

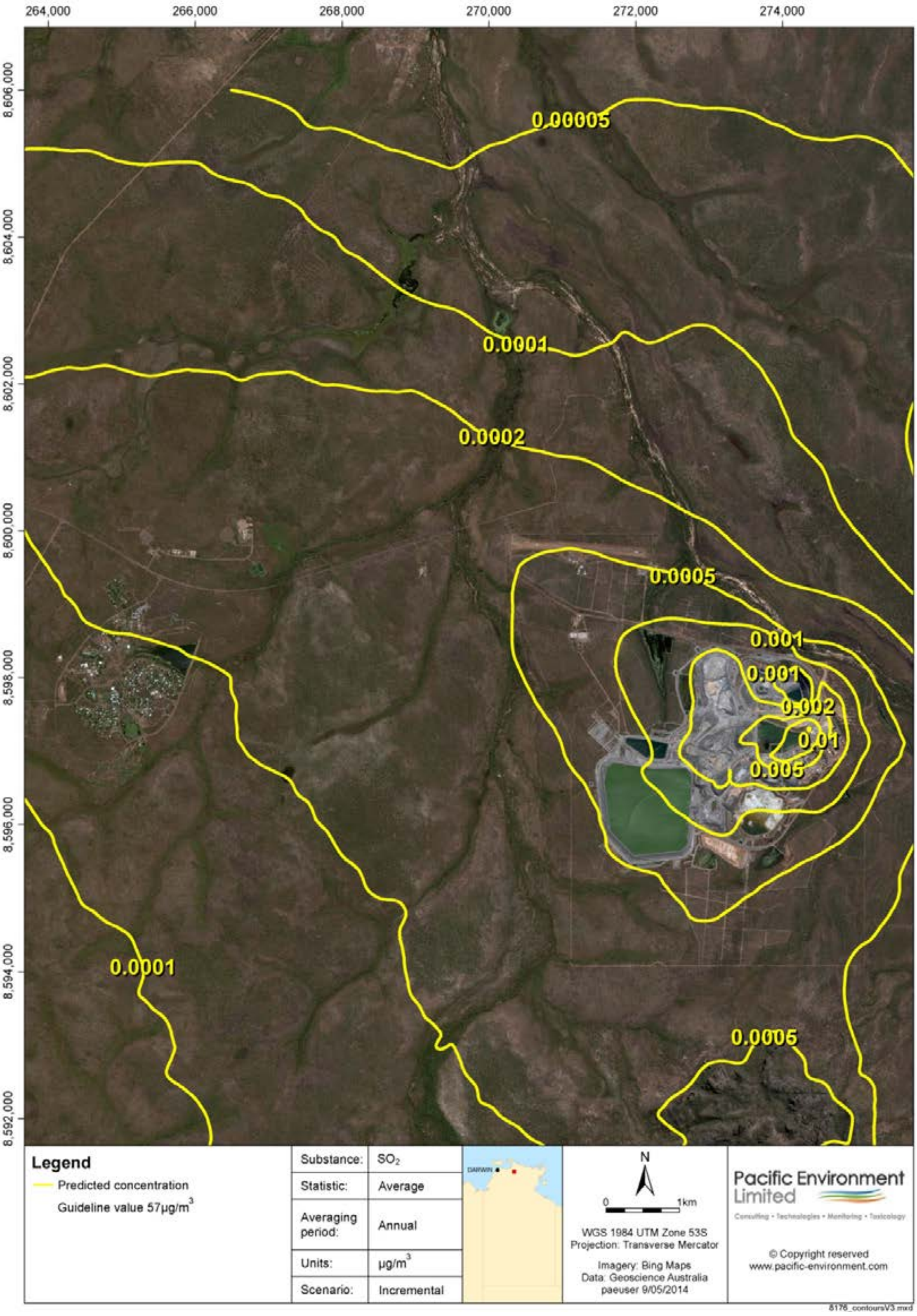


Figure 32 - Incremental SO_2 Concentrations (Annual Average)

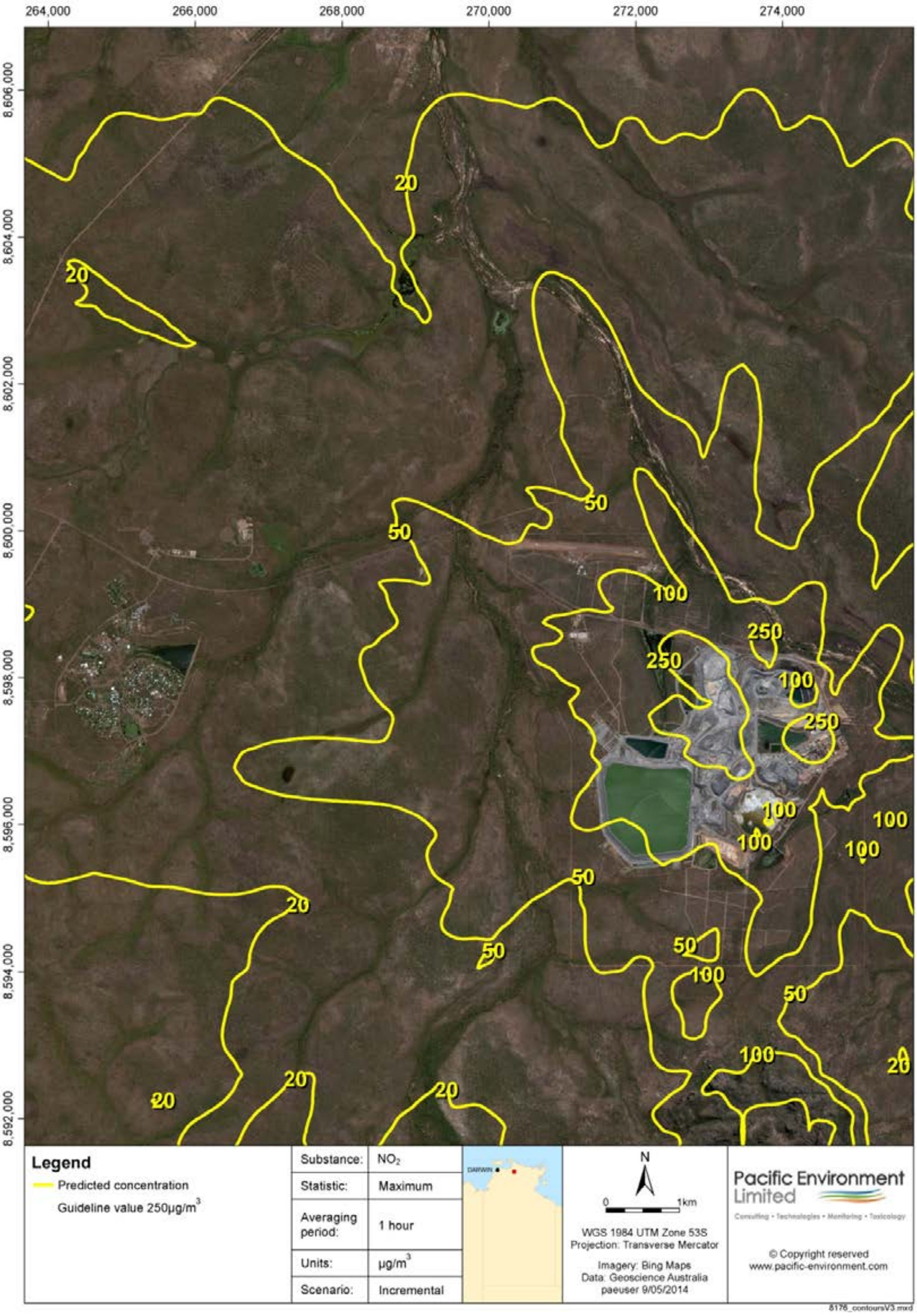


Figure 33 - Incremental Maximum NO_2 Concentrations (1-hr Average)

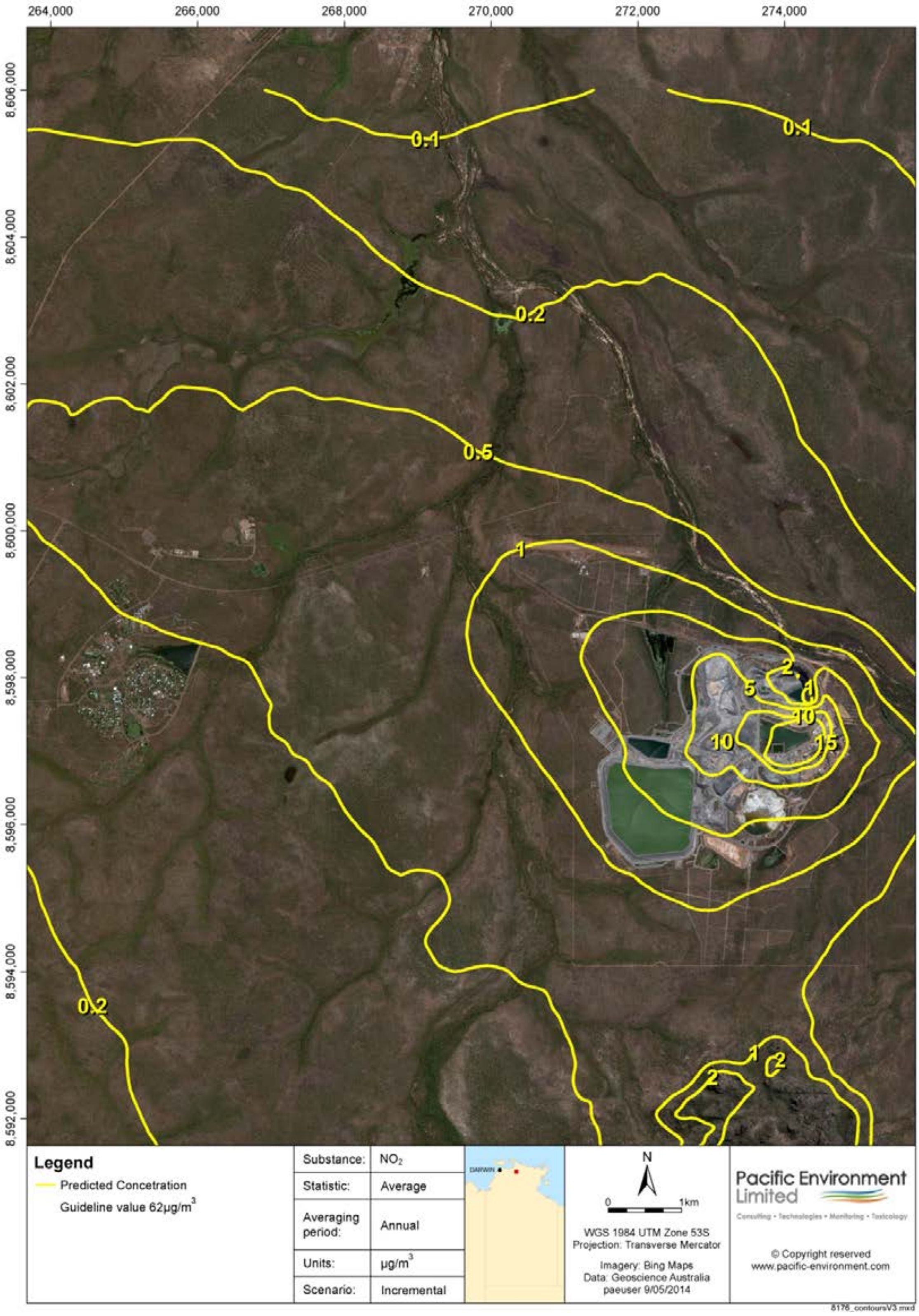


Figure 34 - Incremental NO_2 Concentrations (Annual Average)

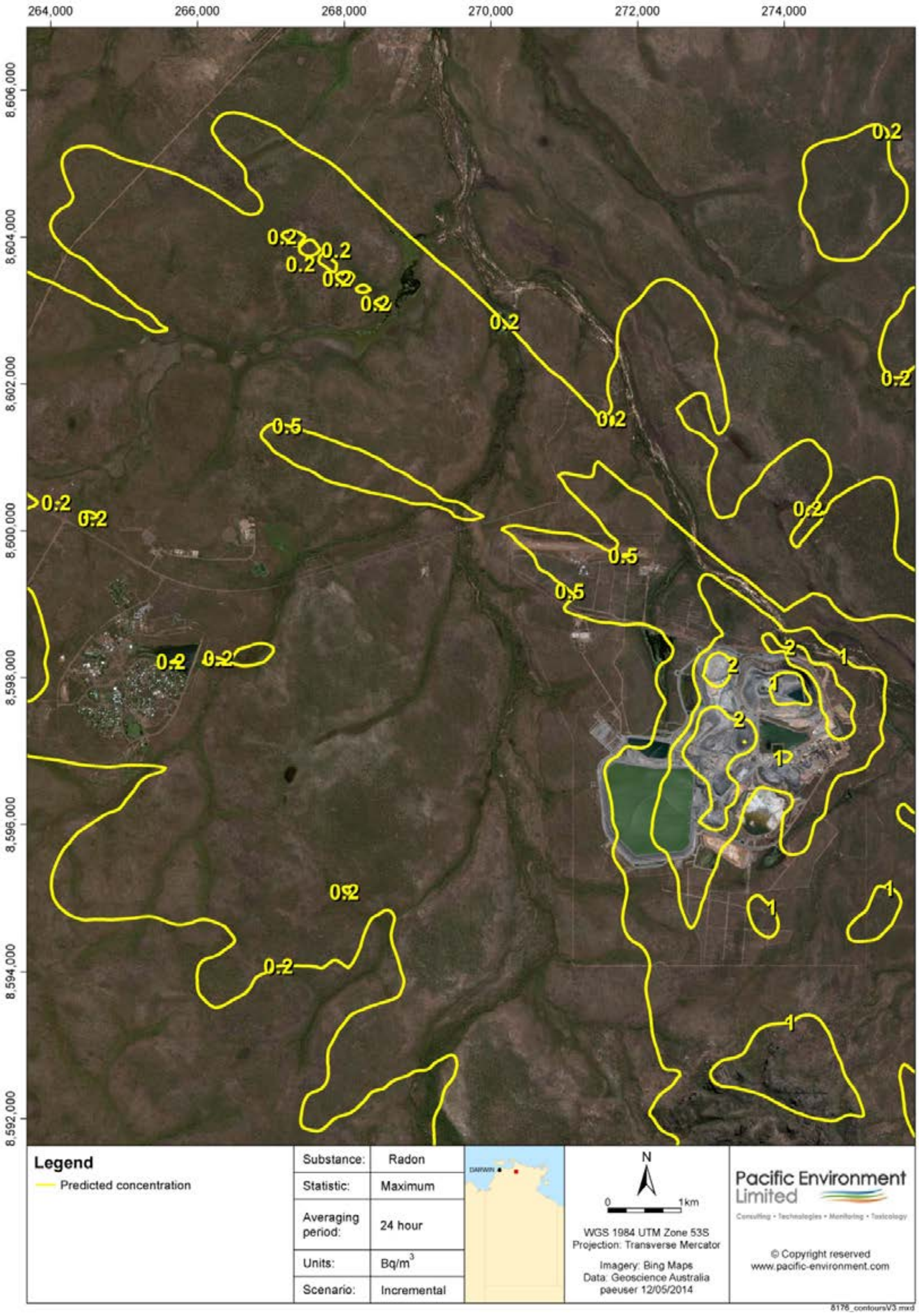


Figure 35 - Incremental Maximum Radon Concentrations (24-hr Average)

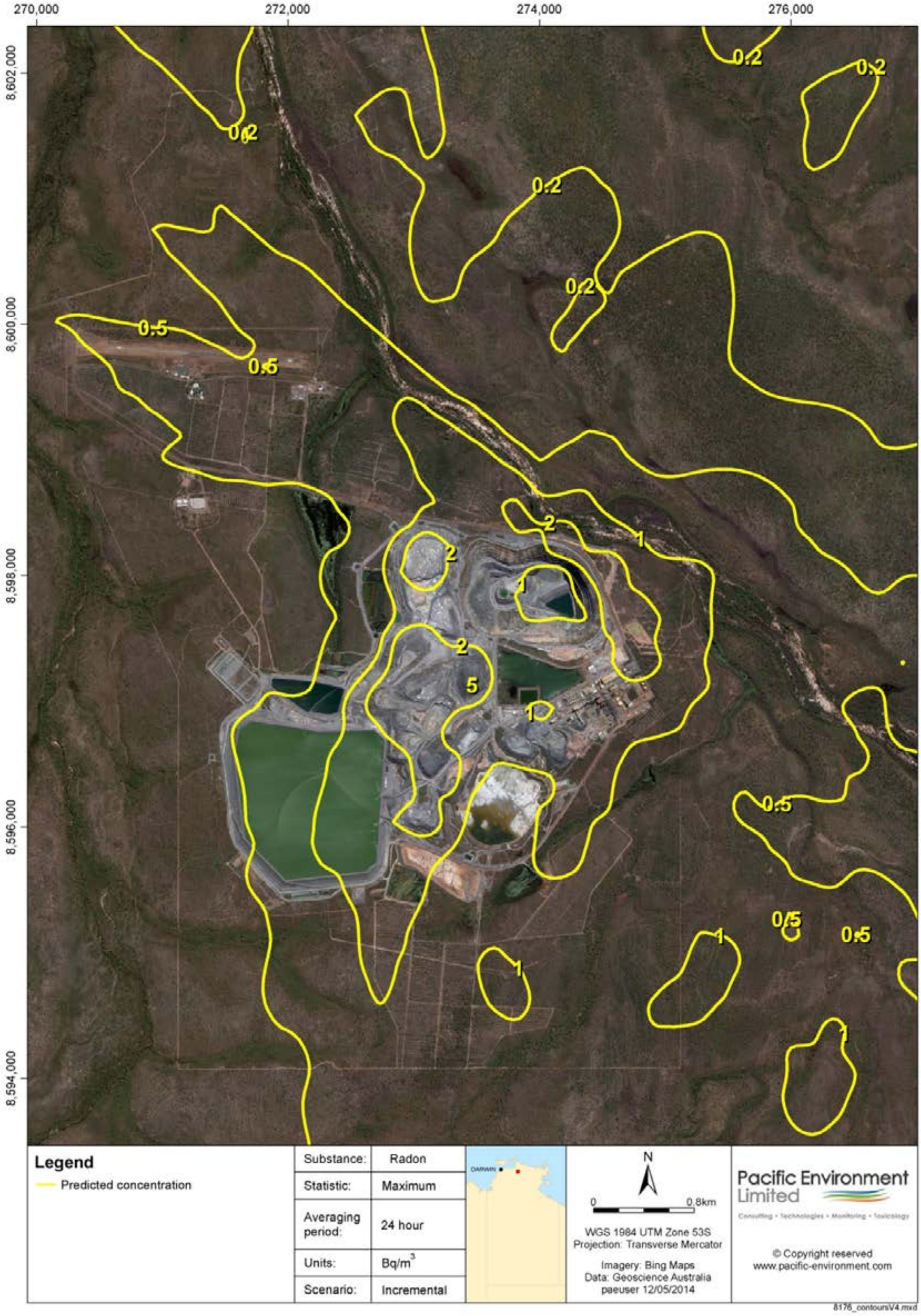


Figure 36 - Incremental Maximum Radon Concentrations (24-hr Average) – Mine Footprint

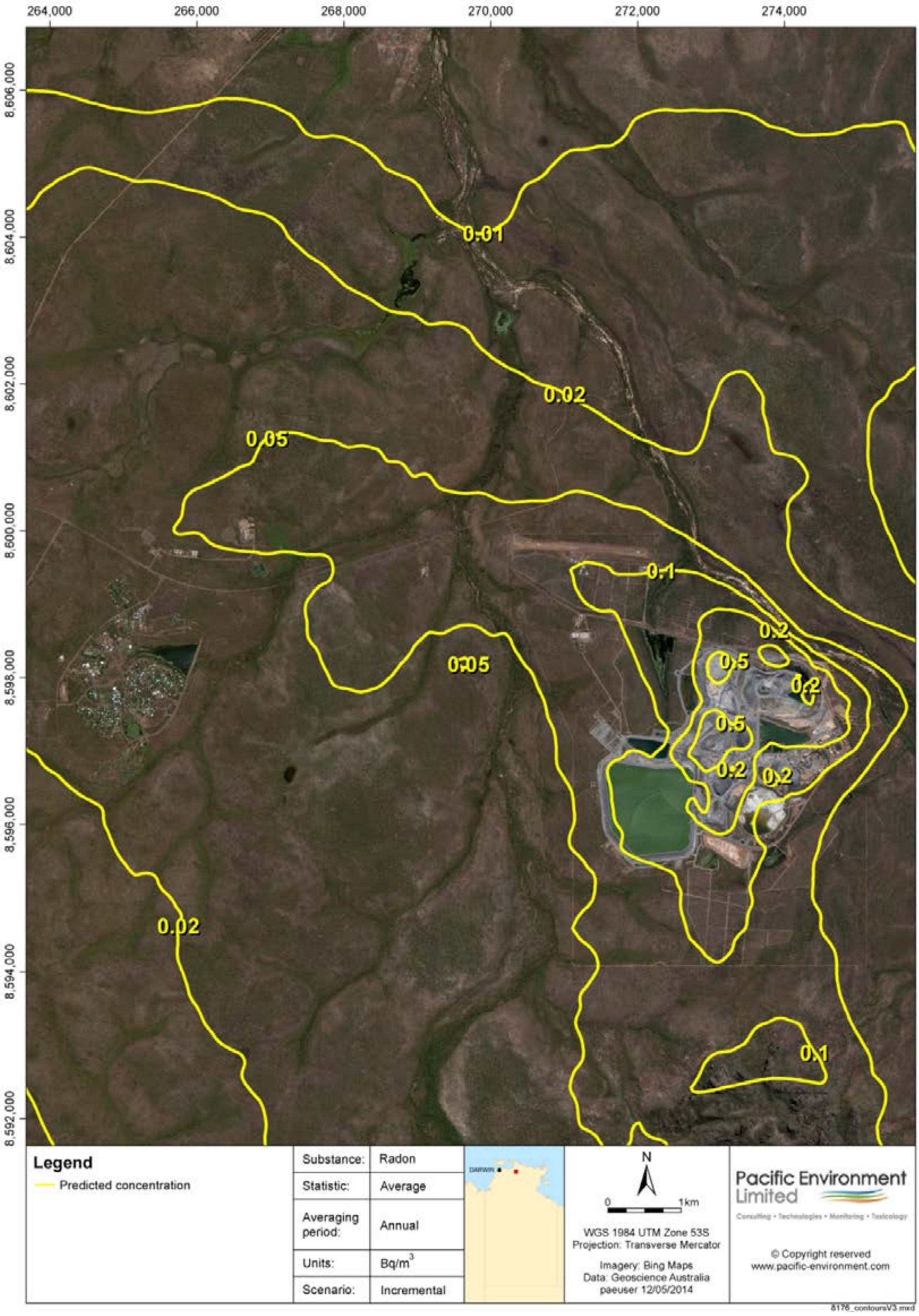


Figure 37 - Incremental Radon Concentrations (Annual Average)

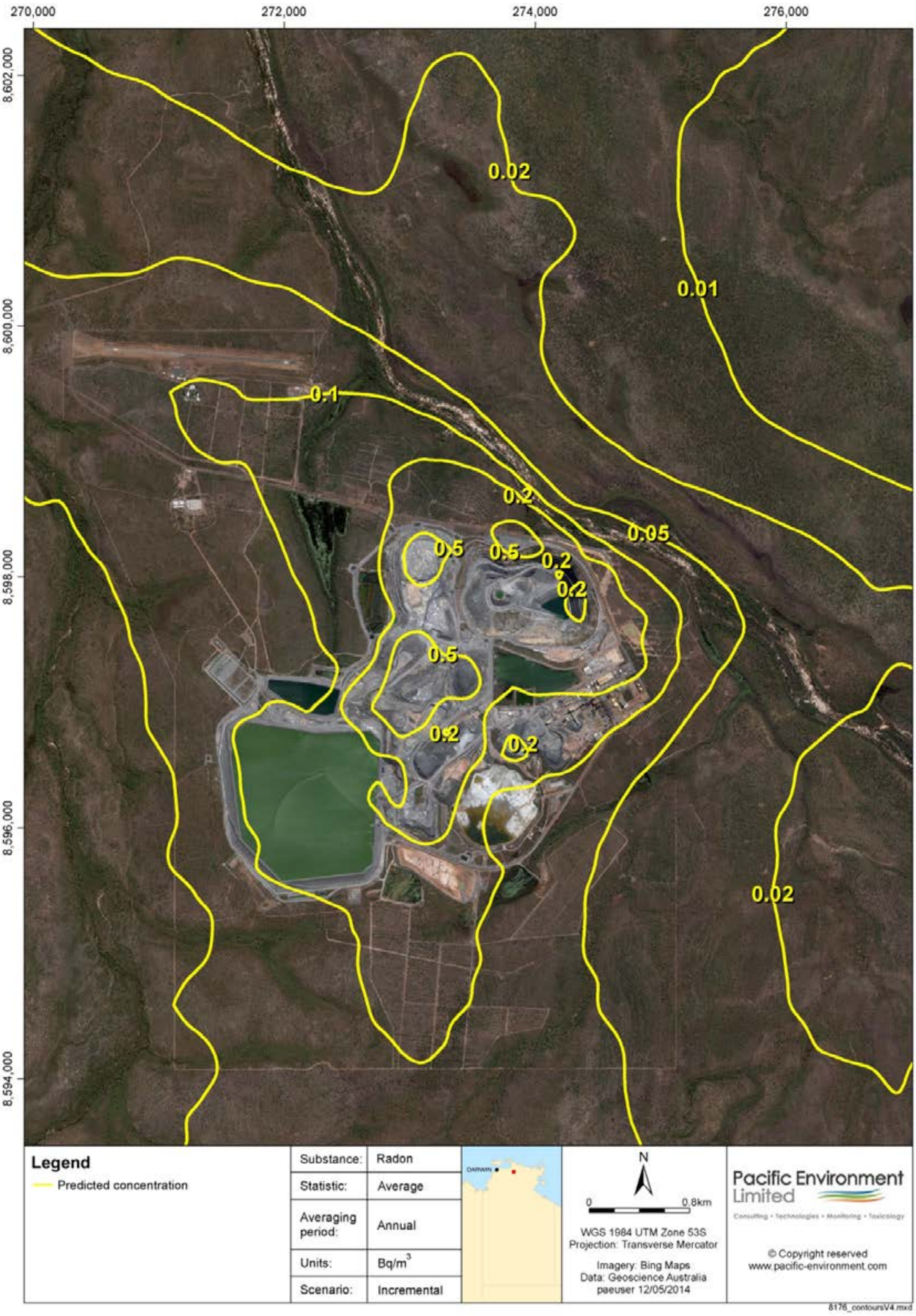


Figure 38 - Incremental Radon Concentrations (Annual Average) – Mine Footprint

14.3 CUMULATIVE IMPACTS

The predicted cumulative ground-level concentrations throughout the study area are presented in Figure 39 to Figure 50.

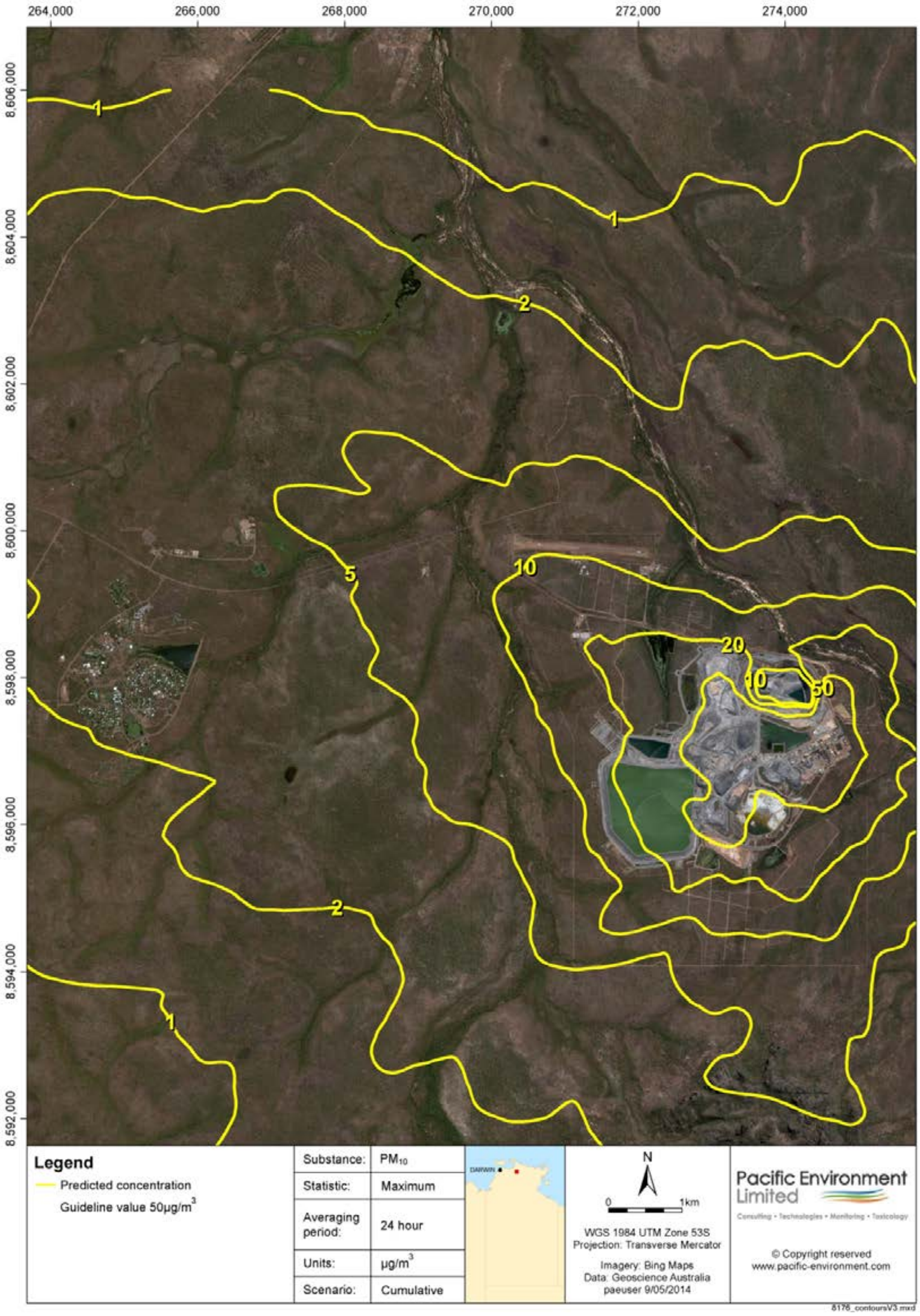


Figure 39 - Cumulative Maximum PM_{10} Concentrations (24-hr Average)

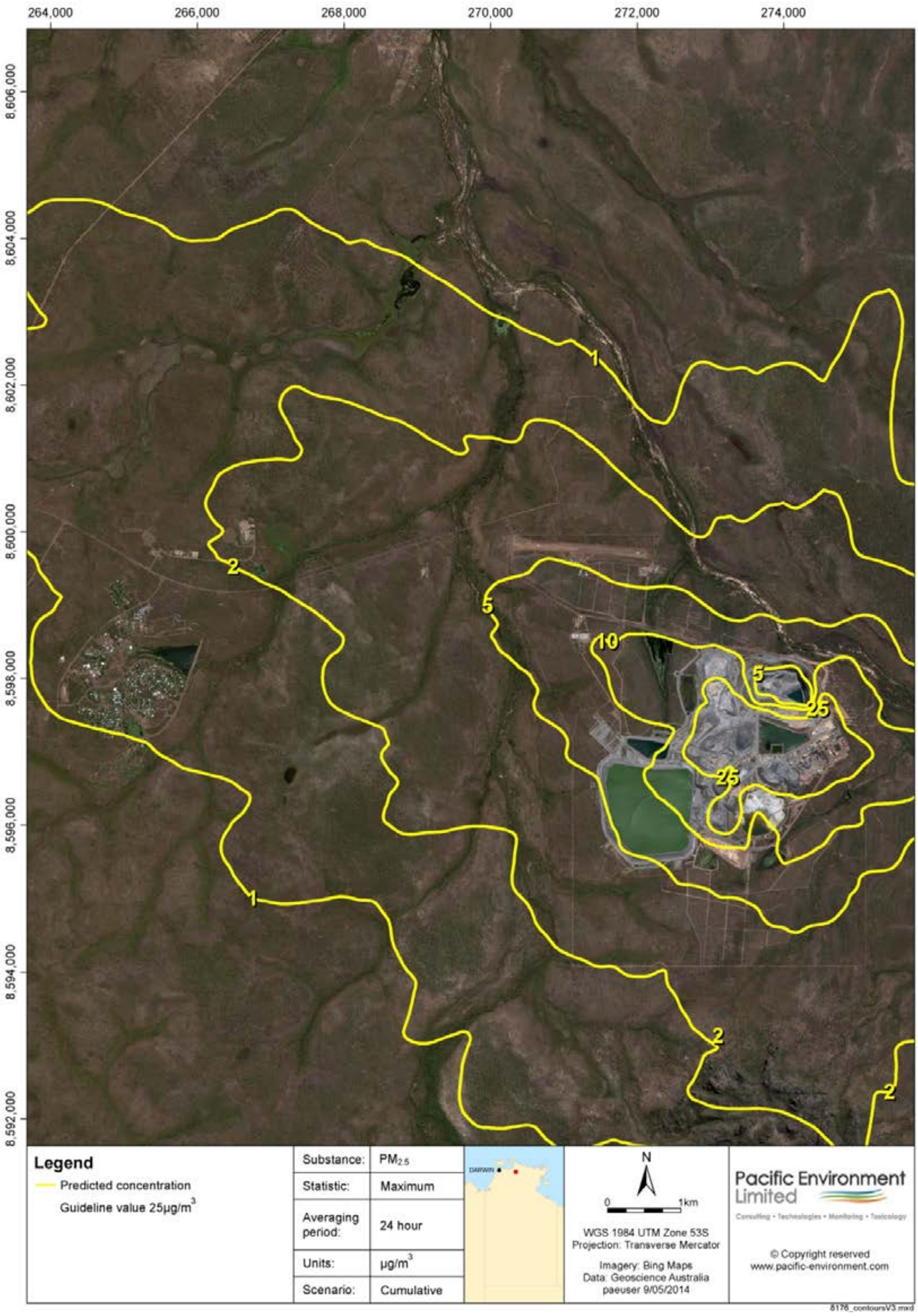


Figure 40 – Cumulative Maximum $PM_{2.5}$ Concentrations (24-hr Average)

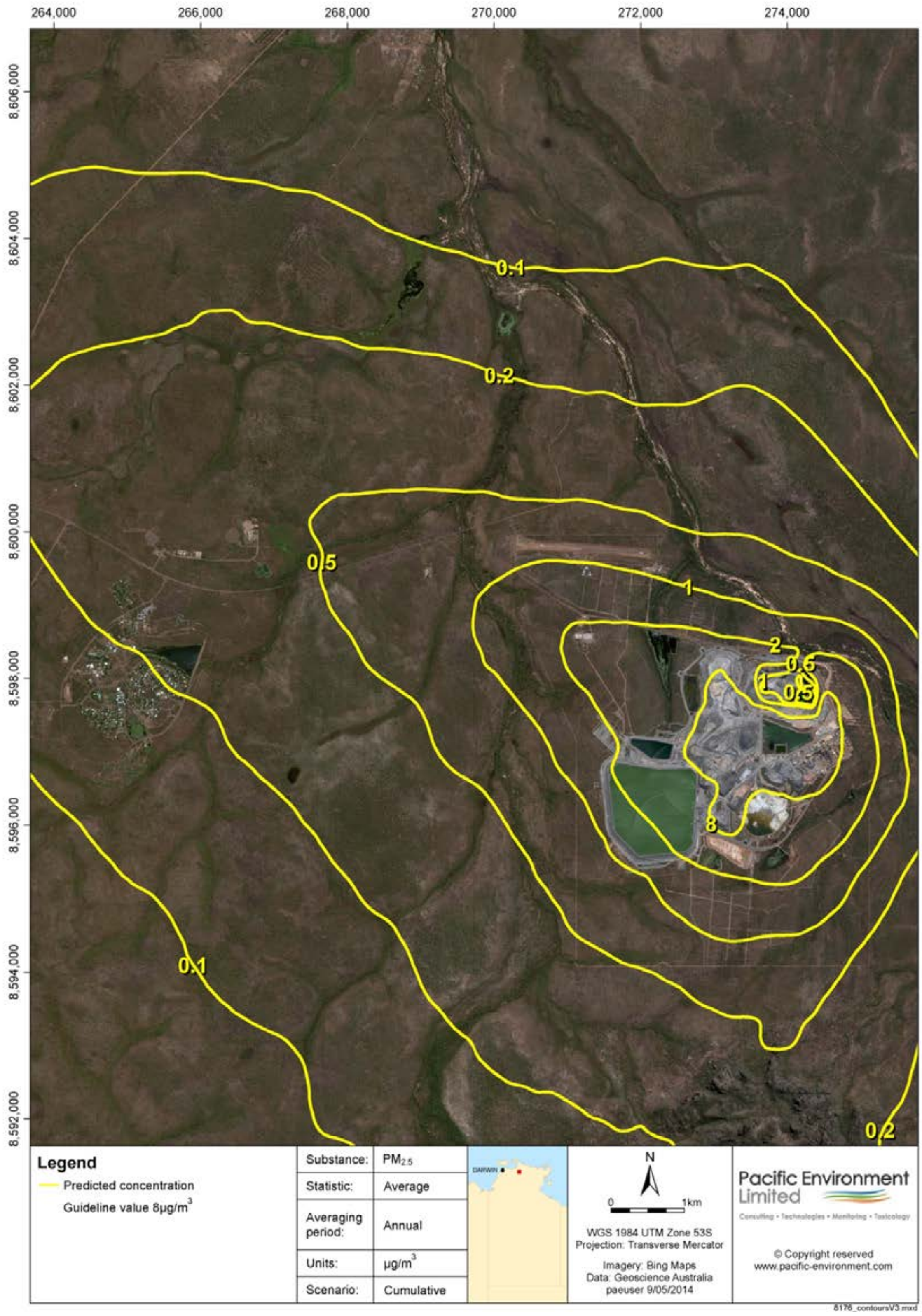


Figure 41 - Cumulative $PM_{2.5}$ Concentrations (Annual Average)

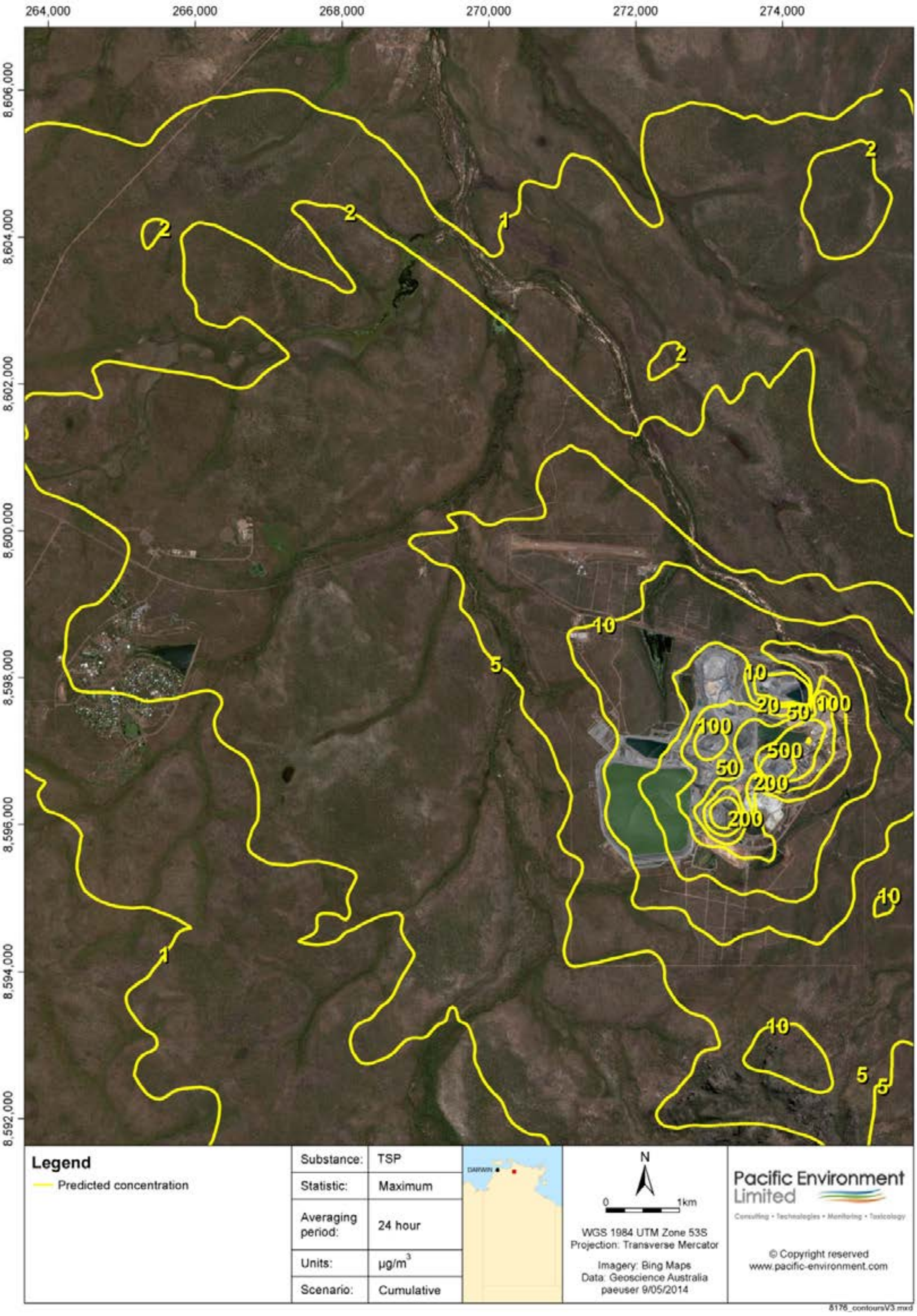


Figure 42 - Cumulative Maximum TSP Concentrations (24-hr Average)

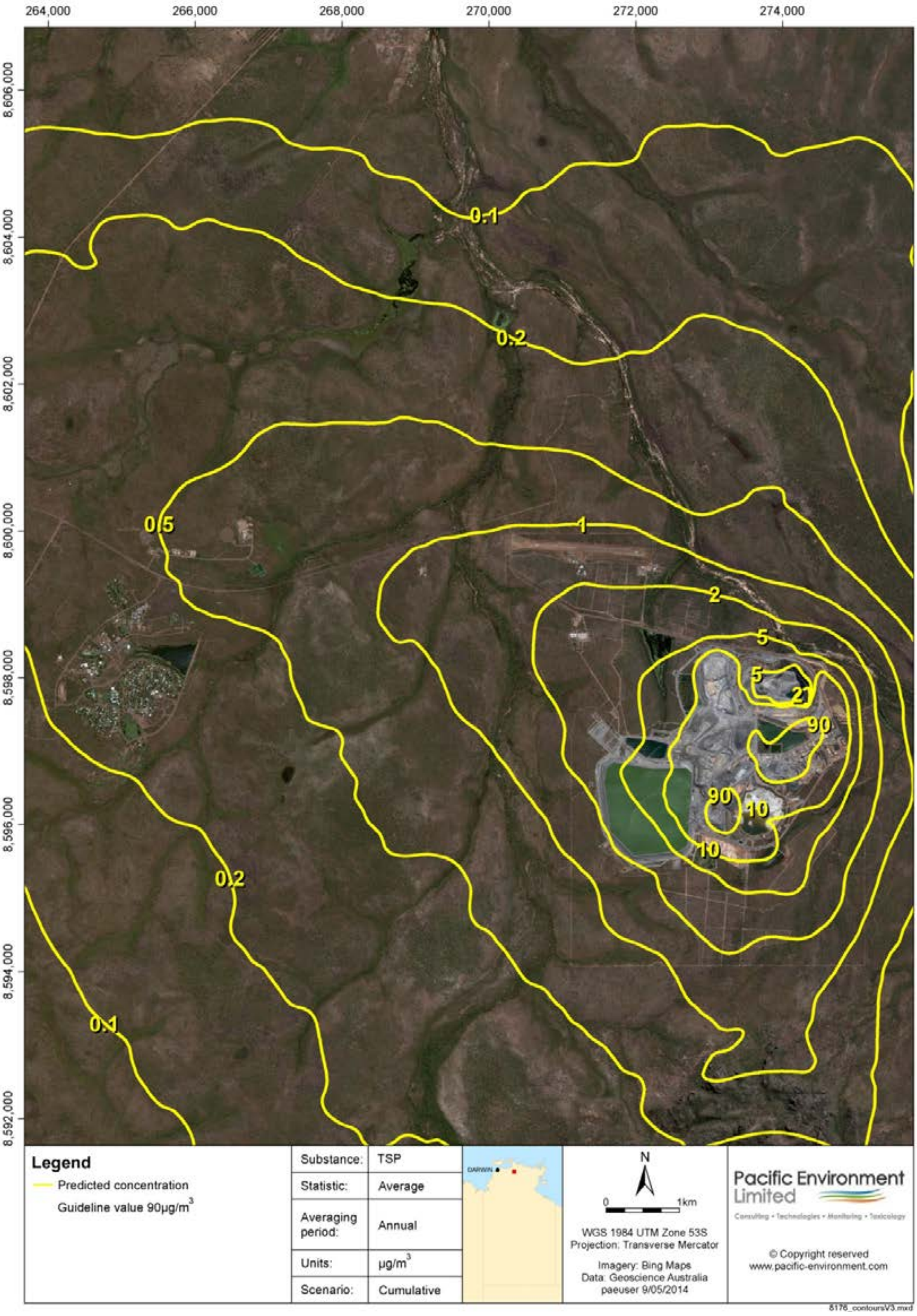


Figure 43 - Cumulative TSP Concentrations (Annual Average)

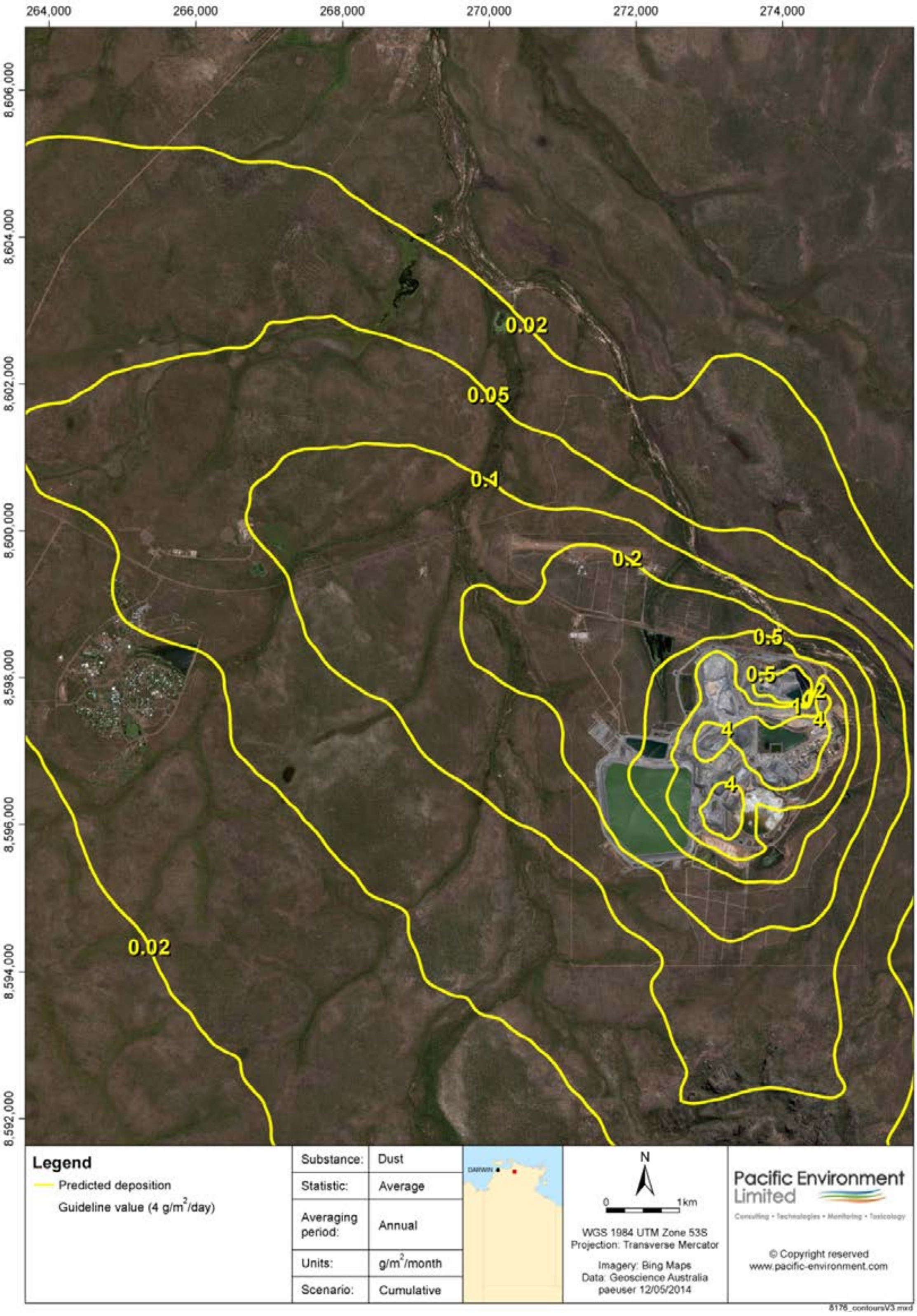


Figure 44 - Cumulative Dust Deposition Rate (Annual Average)

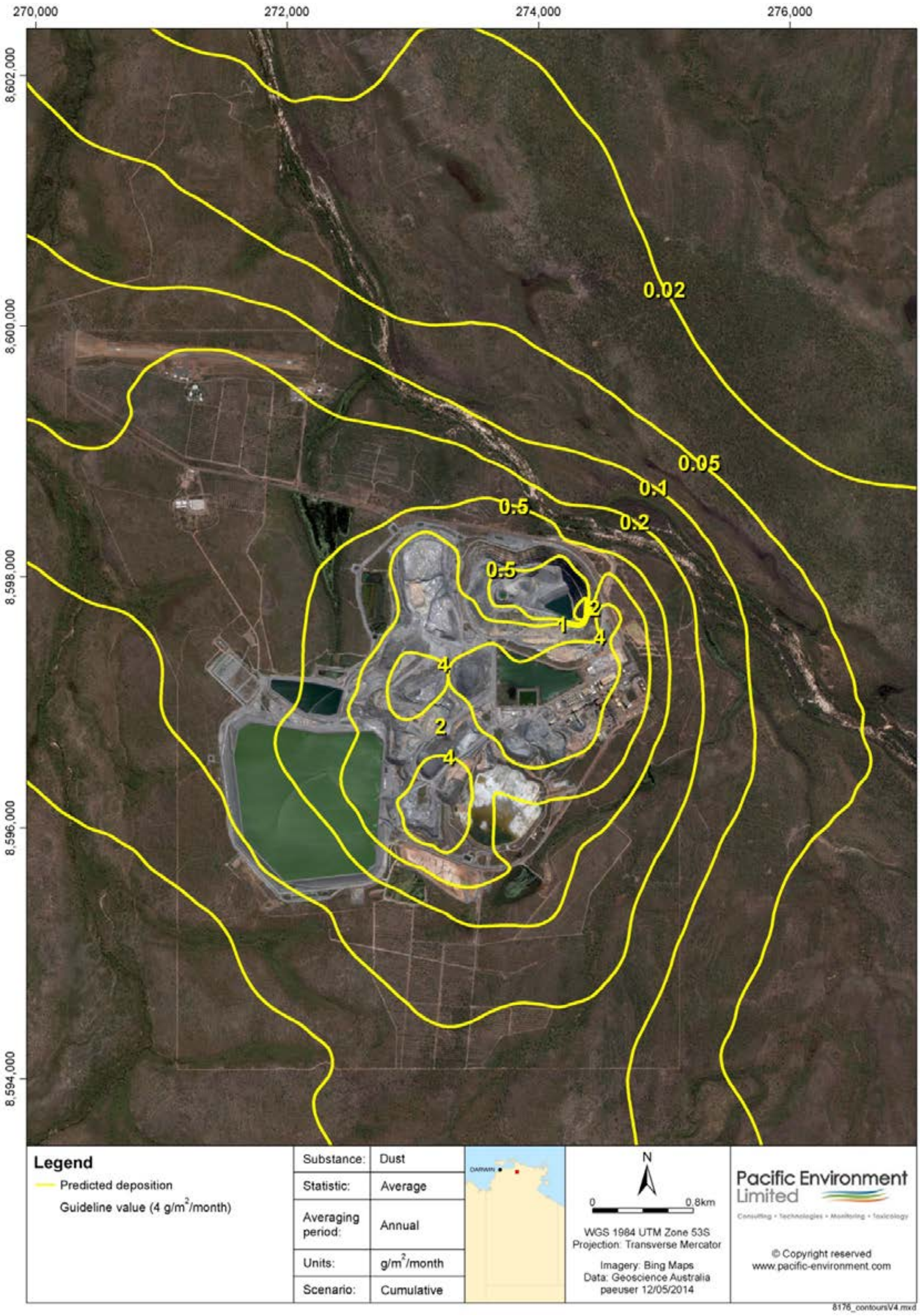


Figure 45 - Cumulative Dust Deposition Rate (Annual Average) – Mine Footprint

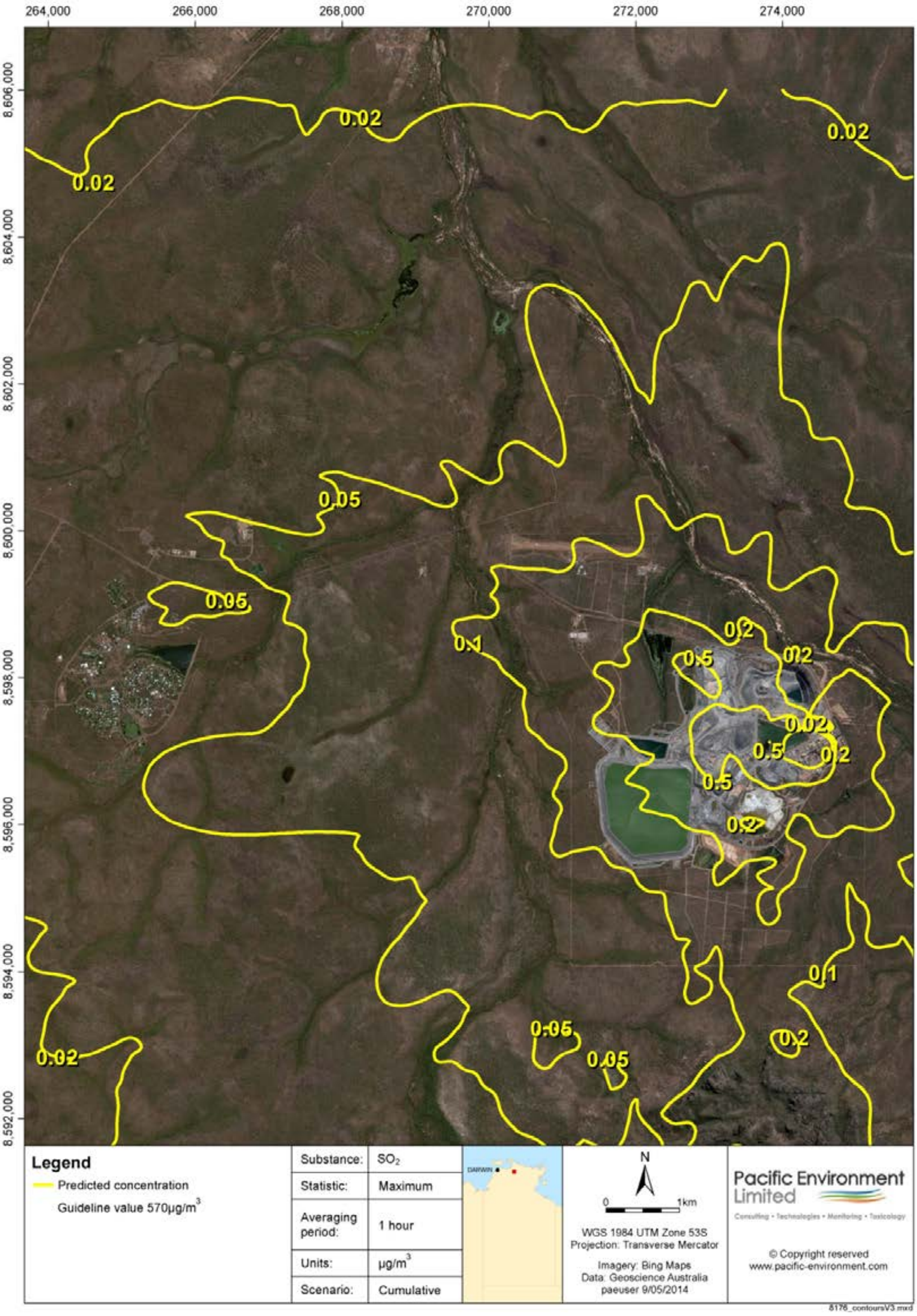


Figure 46 - Cumulative Maximum SO_2 Concentrations (1-hr Average)

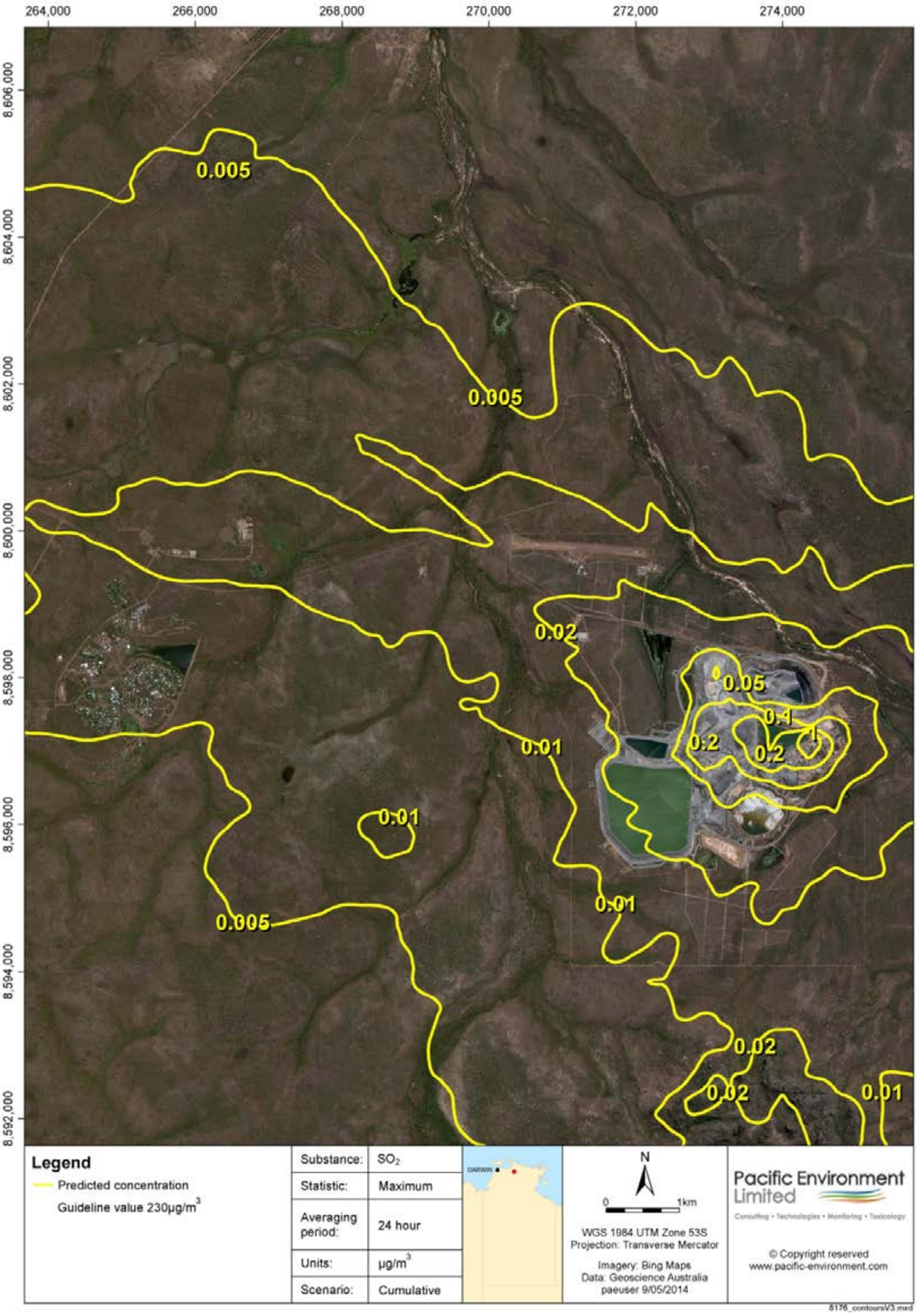
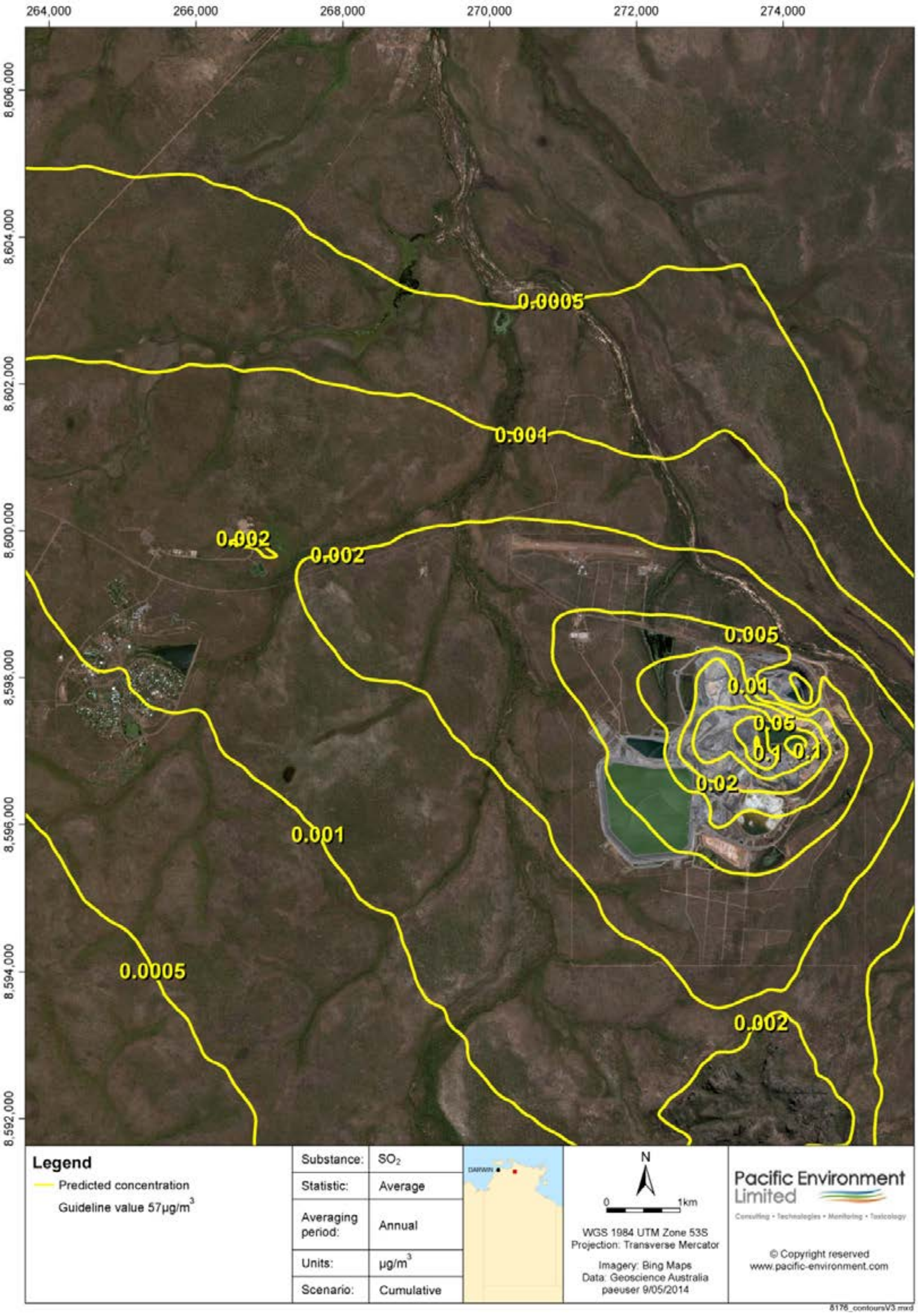


Figure 47 - Cumulative Maximum SO_2 Concentrations (24-hr Average)



Substance:	SO_2
Statistic:	Average
Averaging period:	Annual
Units:	µg/m³
Scenario:	Cumulative

Figure 48 - Cumulative SO_2 Concentrations (Annual Average)

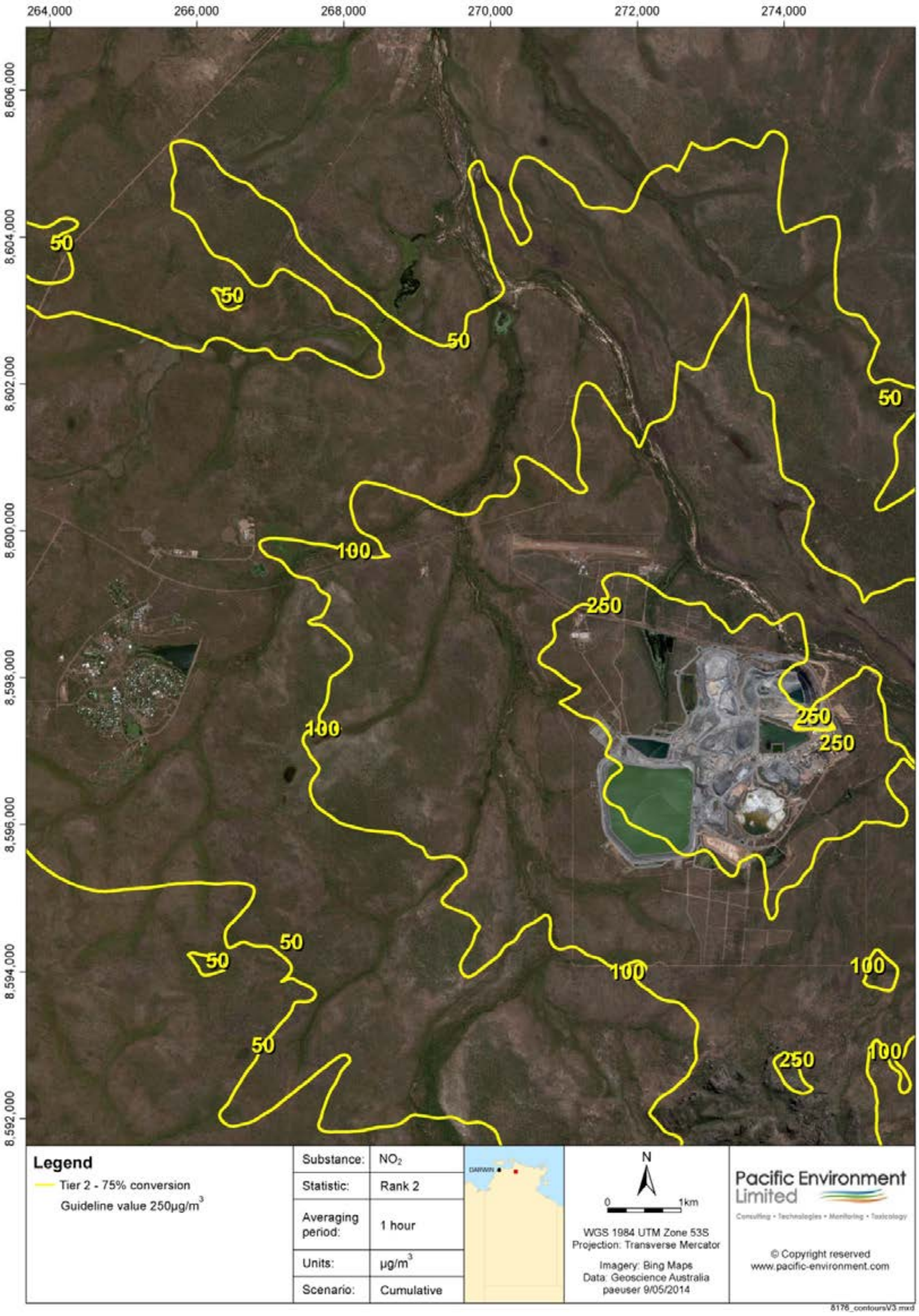


Figure 49 - Cumulative 2nd Highest NO_2 Concentrations (1-hr Average)

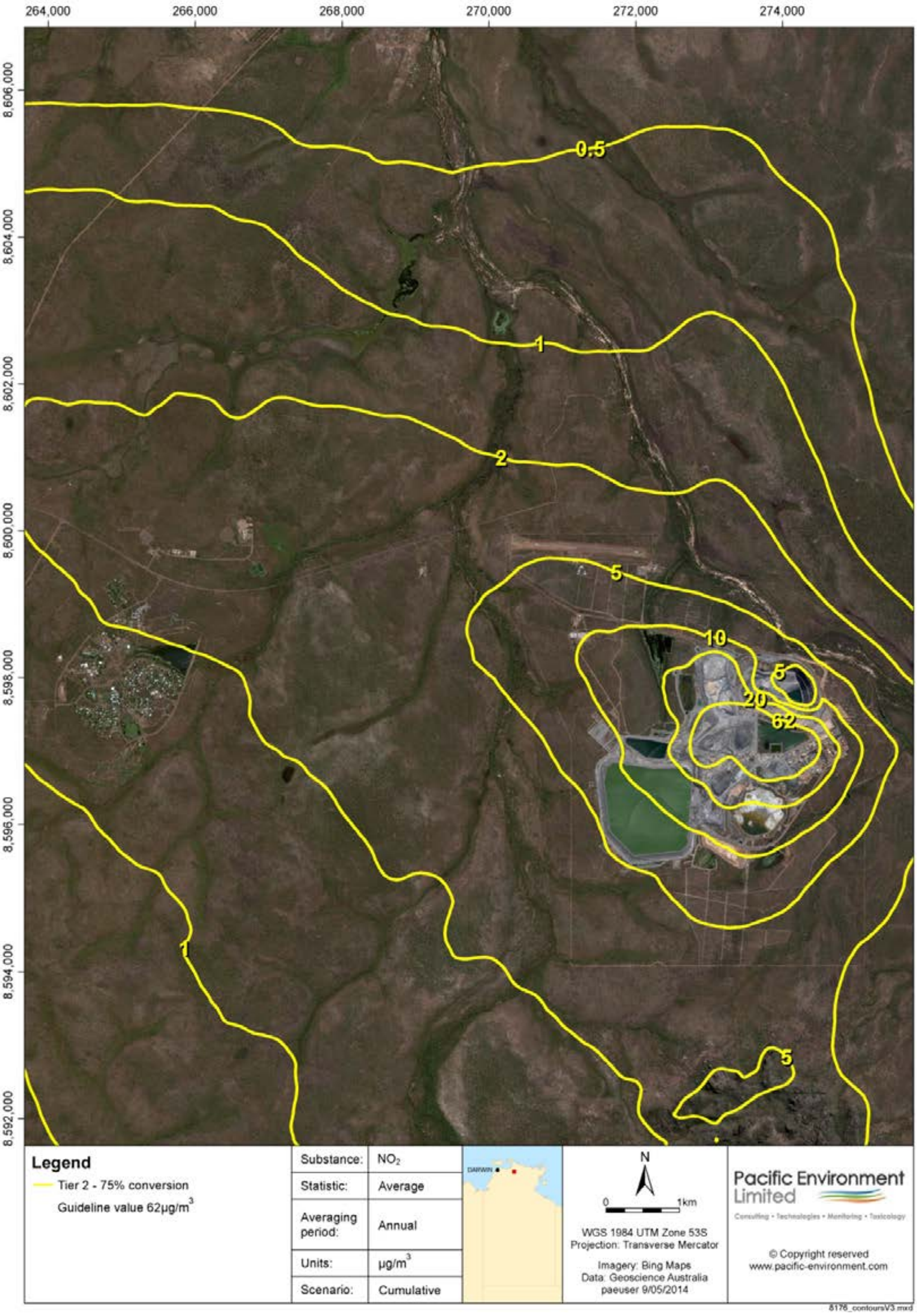


Figure 50 - Cumulative NO_2 Concentrations (Annual Average)