Burrup Rock Art Monitoring Program – Summary of Study Reports

A REPORT TO THE BURRUP ROCK ART MONITORING MANAGEMENT COMMITTEE

- WV03739-MV-RP-0003
- Revision 2
- 4 February 2009

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Executive Summary

Purpose of report

The Burrup Rock Art (the rock art) is located on the Burrup Peninsula (the Burrup) in the Pilbara region of Western Australia. It is of archaeological significance at national and international levels. The Burrup is also the location of a number of industrial activities. In response to concerns expressed regarding perceived possible adverse impacts of industrial emissions to air on the rock art, the Western Australia Department of State Development (DSD) commissioned a range of environmental investigation studies.

This report for the Burrup Rock Art Monitoring Management Committee provides a summary of the findings from these studies in a style that can be easily understood by the general community.

Summary of results

Monitoring of the concentrations of a range of key air pollutants on the Burrup Peninsula was conducted. Only a moderate increase in concentrations from the background sites in the far north of the peninsula to sites closer to industry was found. Concentrations of all gaseous pollutants were low. As expected, airborne fine particle concentrations were elevated close to Parker Point, where ship loading activities are conducted and when the wind direction is likely to transport the dust to the monitoring locations.

Dust collected from surfaces at the southern rock art sites on the Burrup (closer to industrial activity) was consistent with that of iron ore dust. Dust collected from rock art surfaces at the northern sites (far from industrial activity) was consistent with that of local soil-derived dust and sea salt. Deposition rates at all locations were found to be extremely low, close to the limits of detection.

Dispersion modelling of emissions to air from a range of sources on the Burrup was also conducted in 2003. Ground level concentrations and deposition rates of a number of pollutants were presented. Current (most up to date data available at the time of the 2003 modelled scenario) and future predicted scenarios of emissions to air (date unspecified but for a point in time when the proposed additional emissions would likely be operating) were assessed. Concentrations and deposition rates were predicted to increase for the future modelled scenario, in line with the predicted increase in industrial activity on the Burrup Peninsula.

There are no known impact assessment criteria for the impact of air quality to rocks of the type that exist on the Burrup and that contain the rock art. However modelled concentrations from both existing and future scenarios were small relative to assessment criteria for human health and vegetation and the increases due to future emissions were modest. A further study by SKM published in 2009 involved updating and refining the modelling input data and comparing to more recent monitoring data. There were no changes to the conclusions of the previous study in the context of likely impacts to rock art.

Rock samples were subjected in the laboratory (by a process known as fumigation) to concentrations of pollutants at current, future and at five to ten times the future pollutant estimates. There were no changes to the rock surface colour from pollutant concentrations likely to be experienced at the rock art locations.

A microbiological assessment was undertaken by characterising the gross number and diversity of microorganisms on rock surfaces over a four-year sampling period (2004–2008) at five sites close to the industrial emission sources, and at two sites distant.

The conclusion of this study was that there were no evident differences in the gross number and broad diversity of microorganisms associated with samples collected from sites close to and distant from industrial emissions on the Burrup Peninsula.

A key issue of concern is the potential for colour change on the rock art. A study was commissioned to attempt to establish whether evidence of changes in the colour and contrast of images is measurable. Selected petroglyphs were monitored annually over four years with a technique known as reflectance spectroscopy that provides information about the colour and mineralogy.. After examining four successive years of measurement (comprising nearly two and a half thousand individual colour measurements), no perceptible colour change was evident in the colour measurement data.

Each of the measurement points being evaluated for colour change was also characterised with spectral mineralogy to evaluate whether changes in mineralogy are observed on rock surfaces. Reflectance spectroscopy is a technique that provides information about the chemistry of a mineral from its reflected light. Results indicated that the surface mineralogy of the rocks did not change over four years of measurements.

1. Introduction

This report for the Burrup Rock Art Monitoring Management Committee provides a summary of a number of environmental studies associated with the Burrup Rock Art Monitoring Program. The report has been prepared by Sinclair Knight Merz (SKM) under contract to the Western Australia Department of State Development (DSD) (previously the Department of Industry and Resources (DoIR)).

1.1. Project Context

The Burrup Rock Art (hereafter referred to as the 'rock art') is located on the Burrup Peninsula within the Pilbara region of Western Australia. The Burrup Peninsula is the location of a number of major industrial facilities (CSIRO 2007), the most significant (in the context of emissions to air) being:

- the North West Shelf Joint Venture (a liquid natural gas (LNG), domestic gas and liquid petroleum gas (LPG) treatment plant and processing facility, operated by Woodside)
- Hamersley Iron (an iron ore export port)
- Dampier Salt (solar salt fields and export port)
- Burrup Fertilisers (an ammonia plant)
- a range of other gas processing proposals awaiting consideration.

The Burrup Peninsula is characterised by virtually treeless steep ridges and hills comprised of boulders and smaller rocks. The region is recognised as the location of a large number of indigenous petroglyphs, otherwise known as rock art. The images have been created by indigenous peoples by pecking and/or engraving into the surface-weathered coat of the boulders that characterise the Burrup. These petroglyphs have cultural significance for the local indigenous people, as well as being archaeologically important at a national and international level (CSIRO 2007).

1.2. The Burrup Rock Art Monitoring Program

The Burrup and Maitland Industrial Estates Agreement committed the WA Government (the State) to organise and fund a minimum four-year rock art monitoring study and establish an independent rock art monitoring committee.

The Burrup Rock Art Monitoring Management Committee (the Committee) was established by the State in 2002, to independently oversee the scientific studies conducted on the rock art of the Burrup Peninsula. The DSD provides Secretariat support to the Committee.

In 2004, the Committee commissioned a series of studies to investigate the possible effects of current and future industrial emissions on the rock art. These studies included:

- Air Quality, Microclimate and Dust Deposition
- Atmospheric Modelling - Concentrations and Depositions
- Artificial Fumigation
- Microbiological Diversity
- Colour Change and Mineral Spectrometry (Mineral composition).

These studies have now been completed and detailed reports have been published. This document provides a summary of these reports.

1.3. Report Structure

The studies and reports summarised in this report are listed in **Table 1-1**.

Table 1-1 Technical Reports Summarised in this Report

Subject (as defined by DSD)	Title of associated report	Referenced in this report as
1. Air Quality, Microclimate and Dust Deposition	Burrup Peninsula Air Pollution Study: Report for 2004/2005 and 2007/2008. 10th September 2008. CSIRO.	CSIRO 2008a
2. Atmospheric Modelling – Concentrations and Depositions	(i) Burrup Rock Art. Atmospheric Modelling - Concentrations and Depositions. Final. 24/06/2003. SKM. (ii) Burrup Rock Art: Revised Modelling Taking into Account Recent Monitoring Results. Final 1. 12 January 2009. SKM.	SKM 2003 SKM 2009
3. Artificial Fumigation	Field Studies of Rock Art Appearance. Final Report: Fumigation and Dust Deposition. March 2007. CSIRO.	CSIRO 2007
4. Microbiological Diversity	Monitoring of Microbial Diversity on Rock Surfaces of the Burrup Peninsula. Final Report to Burrup Rock Art Monitoring Management Committee. September 2008. Murdoch University.	Murdoch University 2008
5. Colour Change and Mineral Spectrometry (Mineral composition)	Burrup Peninsula Aboriginal Petroglyphs: Colour Change and Spectral Mineralogy 2004-2007. September 2008. CSIRO.	CSIRO 2008b

The remainder of this report (**Section 2** to **Section 6**) summarises each of the above studies. An overview of the rationale for each of the studies is provided, followed by the study objectives, the approach and a summary of the key findings of each study. It should be noted that only a summary of the actual studies are provided, no further interpretation is provided in this summary report.

2. Study 1 - Air Quality, Microclimate and Dust Deposition

This section summarises the results of the air quality monitoring (**Section 2.1**) and microclimate and dust deposition monitoring and assessment (**Section 2.2**) conducted by CSIRO (2008a).

2.1. Air Quality (Monitoring)

An air quality monitoring study was carried out on the Burrup Peninsula by CSIRO between August 2004 and September 2005 and between February 2007 and September 2008. CSIRO 2008a provides the detail and results of this study, which has been summarised in this Section.

2.1.1. Study Objectives

The objectives of this study were to measure concentrations of nitrogen dioxide, sulphur dioxide, ammonia gases and nitric acid, and BTEX (benzene, toluene, ethylbenzene and xylene).

2.1.2. Study Approach

Monitoring occurred at ten sites. One of these was located on the northern Burrup Peninsula, one was on Dolphin Island to the north of the Burrup and one at Mardie Station 81 km southwest of Dampier; these three sites being considered representative of the local background concentrations of gases and particles. One site was located in the town of Karratha, and the other six were located on the lower Burrup Peninsula, near to the industrial areas. **Figure 2-1** shows the location of the monitoring sites.

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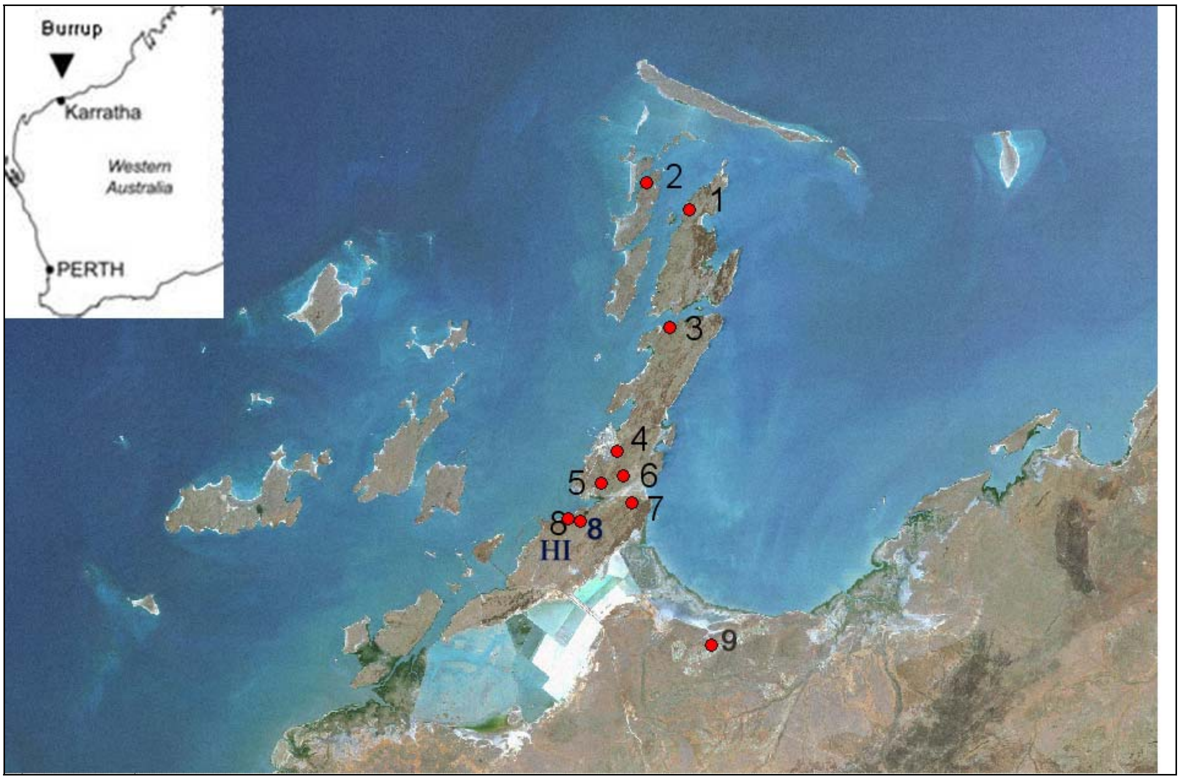

Key: Site 1: Dolphin Island, Site 2: Gidley Island, Site 3: Northern Burrup, Site 4: Woodside East, Site 5: Burrup Road, Site 6: Water Tanks, Site 7: Deep Gorge, Site 8: King Bay South. Site 8HI: Hamersley Iron; Site 9: Karratha. Site 10 is Mardie Station (81 km south west of Dampier) and is not shown.

- **Figure 2-1 Map of the Burrup Peninsula Showing the Air Quality Monitoring Sites. Source: provided to SKM by the Burrup Rock Art Monitoring Management Committee.**

A number of different monitoring methods were applied depending on the target pollutant. Diffusion tubes were used to measure concentrations of sulphur dioxide, nitrogen dioxide, nitric acid and ammonia gases and concentrations of benzene, toluene, ethylbenzene, p+m xylene and o-xylene (collectively known as BTEX). Diffusion tubes are simple passive monitoring devices that have the benefit of being inexpensive and not requiring electricity. Total suspended particulate (TSP) samples were collected at the seven sites located on the Peninsula using Microvol samplers. The filters from these were subsequently analysed to provide the total mass of particles sampled and then chemically analysed for individual pollutant concentrations.

Microvol samplers were also installed at two sites to measure airborne fine particle (PM_{10}) concentrations under particular preset wind directions ie chosen to assess the PM_{10} concentrations resulting from the ore loading procedures at Parker Point. Rainwater samplers were installed at seven sites to collect rainwater during the wet season. The rainwater samples were analysed for pH (acidity) and a range of soluble (acidic) ions.

During one visit to the sites during 2004/2005 an aerosol spectrometer was used to measure the particle number distribution in a number of particle sizes at the sites. Although these measurements were only carried out for a short period they did give some valuable information on the magnitude of dust deposition at the various sites.

2.1.3. Key Study Results and Findings

Concentrations of nitrogen dioxide were low at all sites. The highest monthly averaged concentration at the Burrup sites in 2004/2005 was 3.5 parts per billion (ppb) recorded at Site 5 and 3.8 ppb recorded at site 8 during 2007/2008. Both sites are in the industrial area of the Burrup Peninsula. Site 5 had the highest annual average concentration of 2.4 ppb and 2.8 ppb during 2004/2005 and 2007/2008 respectively.

In contrast to this, the background concentration, defined by the sites on the northern Burrup and at Mardie Station, was about 0.6 ppb. There was an obvious although small gradient in concentration between the background nitrogen dioxide concentrations and those in the industrial sector.

There were some small increases in ammonia gas concentrations at sites 5, 6, 7 and 8 which are located near to industry. At site 5 the increase was due almost entirely to one month in June/July when the concentration averaged 3.0 ppb. Local background concentrations, deduced from sites 1, 3 and 10 during 2004/2005 and 2007/2008 were ammonia 0.5 ppb, nitrogen dioxide 0.6 ppb, sulphur dioxide 0.116 ppb and nitric acid 0.154 ppb. The site located in Karratha had higher concentrations than any of the other sites, but this was deemed most likely due to the more urban nature of the site.

The concentrations of ammonia, nitrogen dioxide, sulphur dioxide and nitric acid were very low compared with measurements made at other remote locations.

BTEX concentrations were also very low at all sites and for all sampling periods. The benzene concentration at the background sites 1, 3 and 10 was about 0.019 ppb and the average at the other sites about 0.021 ppb. Benzene, and other BTEX gas concentrations, showed little enhancement over the background levels.

Monthly average nitric acid concentrations ranged from 0.021 ppb at Site 10 to 0.632 ppb at Site 9. The background nitric acid concentration was about 0.155 ppb compared with 0.229 ppb which was the average in the industrial sector, at Sites 4, 5, 6, 7 and 8. Again, there is little evidence of a gradient between background nitric acid concentration and that in the industrial sector.

Sulphur dioxide concentrations were also very low during 2004/2005 and monthly average concentrations ranged from 0.019 ppb at Site 10 to 0.367 ppb at Site 4. The annual average sulphur dioxide concentration in the industrial area was 0.175 ppb and the maximum annual average

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concentration was 0.215 ppb at Site 5. These results suggest that the gradient of sulphur dioxide concentration between background sites and those in the industrial sector is low. Monthly average nitric acid concentrations ranged from 0.021 ppb at Site 10 to 0.632 ppb at Site 9. The background nitric acid concentration was about 0.155 ppb compared with 0.229 ppb which was the average in the industrial sector, at Sites 4, 5, 6, 7 and 8. Again, there was little evidence of a gradient between background nitric acid concentration and that in the industrial sector. The sulphur dioxide and nitric acid concentrations measured during 2007/2008 were very similar to those measured during 2004/2005.

Annual average TSP concentrations ranged from 21.8 micrograms per cubic metre ($\mu g\ m^{-3}$) at Site 3 to 51.1 $\mu g\ m^{-3}$ at Site 8. Sites 1 and 3 represent the background TSP concentrations and the average of those was about 22 $\mu g\ m^{-3}$ compared with an average of 34 $\mu g\ m^{-3}$ for the sites on the lower Burrup area. The TSP loadings at site 8 were higher than other sites, and probably originated from activities at Parker Point. At various sites the influence of TSP derived from iron ore transport and loading was investigated by measuring the iron and sea-salt fractions of TSP. This showed that compared to other sites, Site 1 was least influenced by iron ore loading and transport and was most influenced by sea-salt. At Site 8, close to Parker Point, the iron fraction of the TSP was the highest, compared with other sites and the sea-salt fraction the lowest, indicating that TSP from ore loading was a significant fraction of the total TSP. High frequency PM_{10} concentrations measured at Site 8 showed significantly higher concentrations when the wind came from the Parker Point or from the local road, again indicating that ore loading at Parker Point increases the PM_{10} concentrations at Site 8.

2.2. Microclimate and Dust Deposition

The microclimate of a particular location will closely influence the amount of dust that will be deposited and retained upon a rock surface, and thereby potentially influencing the impact on the colouration of the rock surface.

2.2.1. Study Objectives

To measure:

- temperature and humidity
- rainwater (amount and composition, including pH and soluble ions)
- total suspended particles (TSP) and PM_{10}
- dust deposition rates
- total acid deposition rates (by calculating the wet and dry deposition of all nitrogen and sulphur species in the gas and aqueous phases).

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2.2.2. Study Approach

Monitoring equipment to assess the micro-climate (temperature, humidity and rainwater) were co-located with the air quality samplers at seven sites (Dolphin Island, North Burrup, Woodside East, Burrup Road, Water Tank, Deep Gorge and King Bay South).

Dust deposition rates were measured/determined at six sites (Dolphin Island, Woodside East, Burrup Road, Water Tank, Deep Gorge and King Bay South).

Dust (as TSP) was measured at seven sites (Dolphin Island, North Burrup, Woodside East, Burrup Road, Water Tank, Deep Gorge and King Bay South) and PM_{10} was measured at two sites (King Bay South and Hamersley Iron). TSP samples were also analysed for a collection of elements.

Wind speed and wind direction was also measured at King Bay south site.

2.2.3. Key Study Results and Findings

The key findings were:

- the background (away from industrial locations) dust deposition rate was about 10 milligrams per metre square per day (mg m^{-2} day^{-1}) compared with 69 mg m^{-2} day^{-1} measured at Site 8 (adjacent to Parker Point) and an average of 32 mg m^{-2} day^{-1} for the wider industrial area of the Burrup
- the total acid deposition rate from nitrogen and sulphur of 14 milliequivalents (meq) m^{-2} yr^{-1} is typical for areas of the Burrup peninsula which have no or little anthropogenic influences
- at the sites close to industrial influences the acid deposition rate was 20 – 24 mg m^{-2} day^{-1} in 2004/2005 and 21 – 33 mg m^{-2} day^{-1} in 2007/2008. This slight increase is due largely to an increase in the amount of rainfall in the latter period, and on the Burrup Peninsula this appears to be the major variable in the amount of acid deposited. Although the additional acid deposited from the background to the industrial areas is observable it is small.

The study concluded that acid deposition to the Burrup area is unlikely to cause any adverse effects to rock or rock art on the Burrup Peninsula.

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3. Study 2 - Atmospheric Modelling

3.1. Overview

The primary dispersion model used was The Air Pollution Model (TAPM), developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) of Australia. This model is commonly used in Australia for air dispersion modelling studies. The study predicted emissions, transport and subsequent ground level concentrations and deposition rates of the following pollutants deemed to have a possible impact to the rock art:

- nitrogen oxides (NO_x) and nitrogen dioxide (NO_2)
- sulphur dioxide (SO_2)
- ammonia (NH_3).

3.2. Assessment scenarios

The assessment considered two scenarios, existing sources and a future case. Existing sources of emissions to air at the time of the assessment in 2003 included:

- Woodside Onshore Treatment Plant (OTP)
- Hamersley Iron Power Station
- Shipping

The 2003 modelling was used as a basis for deciding on control and industry-affected sites rock art monitoring sites. It was also used to provide information concerning concentrations of air pollutants experienced by rock art if any changes were noted during the monitoring program.

The future case included emissions to air from:

- Woodside OTP with additional processing ‘trains’ 4 and 5
- Hamersley Iron (HI) Power Station
- Methanex (two 2-million tonnes per annum (Mtpa) trains), GTL, Burrup Fertilisers, Dampier Nitrogen, Japan Dimethyl Ether (DME) and two other industries (at HI Land) equivalent to Japan DME and Dampier Nitrogen
- current and potential shipping

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3.3. Results

3.3.1. Model Validation

Summary results (annual and maximum hourly concentrations) of NO_x compared well to monitored concentrations at Dampier.

The TAPM model significantly over predicted concentrations of NO_2 as measured at Dampier (by up to 100% for short term concentrations). This was deemed to be due to a conservative estimate within TAPM of the conversion rate of NO (as emitted from the pollution sources) to NO_2 over time.

3.3.2. Ground Level Pollutant Concentrations

Highest modelled SO_2 concentrations were closely correlated to the location of shipping berths, as shipping is the main source of SO_2 emissions in the area. The sulphur originates from the fuel oil used by the ships, which has a high percentage of sulphur. Given the poor dispersion of shipping emissions (due to relatively low temperatures and low heights of ship funnels) maximum concentrations of SO_2 are found close to the shipping berths. This contrasts to NO_x emissions from the Woodside onshore treatment plant and from the Hamersley Iron Power Station, which are much hotter emissions from much higher release points (high chimneys/stacks) which aids the dispersion of NO_x and causes maximum concentrations to be located further away from these sources.

The maximum annual NO_2 concentration as a result of emissions from existing sources is 2.7 ppb; from future sources this increases to 5.2 ppb. Maximum annual SO_2 concentrations increase from 0.5 ppb as a result of emissions from existing sources to 1.6 ppb for future sources.

3.3.3. Pollutant Deposition

Maximum predicted deposition rates were as follows.

- Up to 0.26 kg of nitrogen per hectare per year from existing sources of NO_2 and 0.64 kg of nitrogen per hectare per year from future sources of NO_2.
- 1.7 kg of SO_2 per hectare per year from existing sources and 2.6 kg of SO_2 per hectare per year from future sources.
- Up to 3.3 kg per hectare of nitrogen as a result of future emissions of ammonia.

3.3.4. Modelling Update Study

In 2008 SKM was commissioned by DSD to conduct a further study (SKM 2009). The objectives were to:

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- revise the previous modelling study to cover the periods for which air quality monitoring was undertaken (2004/5 and 2007/8) via a separate study
- revise estimates of industrial emissions using available public documentation of Burrup industrial developments, to represent actual industrial operations during the monitoring period
- analyse modelling results of concentrations and depositions of NO_2 and SO_2 and compare to the results from the monitoring program.

Air quality monitoring has been conducted at ten sites via a separate study (CSIRO 2008a). Two of these were located on the northern Burrup Peninsula and one at Mardie Station 81 km southwest of Dampier. These sites were considered to be representative of the local background concentrations of the key pollutants. One site was located in the town of Karratha, and the other six were located on the lower Burrup Peninsula, near to the industrial areas. The sampling equipment used was so-called 'passive sampling' otherwise known as diffusion tubes. SKM (2009) notes that the uncertainty associated with this type of equipment is relatively high. However (as stated in **Section 2.2.1**), this equipment has the benefit of being inexpensive and not requiring electricity and therefore being able to be deployed at a larger number of locations.

The results of the modelled concentrations, for the current and future modelled scenarios, and the air quality monitoring/measured results, for the key pollutants NO_2 and SO_2, are presented in **Table 3-1**.

- **Table 3-1 Modelled annual average ground level concentrations (in parts per billion) averaged across the air quality monitoring sites for current and future modelling scenarios (SKM 2009)**

Year	NO_2			SO_2		
	Current modelled	Future modelled	Measured	Current modelled	Future modelled	Measured
2004	1.33	2.20	1.97	0.46	0.52	0.18
2005	1.36	2.04	1.69	0.49	0.53	0.15
2007	1.24	1.32	1.83	0.33	0.20 [(a)]	0.17
2008	1.86	2.37	1.98	0.58	0.63	0.19

(a) The reason for this decrease is that measured and therefore modelled concentrations did not cover the full calendar year.

In general, **Table 3-1** shows concentrations of both pollutants are predicted to increase from the current to the future scenario. For NO_2, measured concentrations are significantly in excess of modelled concentrations whereas for SO_2 the opposite is true. These differences are likely to be a reflection of a combination of both the monitoring equipment used and the assumptions used by the model. Actual numbers, relative to known impact assessment criteria for human health and vegetation, and concentrations in urban areas, are very small. There are no known impact assessment criteria for air quality and deposition impacts to rock art.

4. Study 3 - Artificial Fumigation and Dust Deposition

4.1. Fumigation

Fumigation chamber studies on typical rock samples from the Burrup Peninsula were carried out on current, future and at 5 to 10 times the future pollutant estimates (CSIRO 2007). In order to evaluate the role that dust may play in rock surface modification, duplicate experiments were run involving the addition of dust to rock surfaces. The results of the fumigation experiments and exposure studies involving extreme exposure scenarios with concentrated pollutants (organic solvents and acids) applied to rock minerals resulted in few mineralogical phase changes.

4.1.1. Study Objectives

To determine if airborne emissions from industrial activities could affect the rock art. To investigate changes (if any) in the weathered rock surface and the engraved surface. To assess physical, chemical and mineralogical changes with emphasis on determining early indicators of damage.

4.1.2. Study Approach

Fumigation chamber studies on typical rock samples involving exposure of rocks at current, future, 5-10 times future and elevated levels of pollutants (concentrated solutions) with cycles of heating, wetting and drying (designed to emulate natural diurnal cycles).

Pollutants included nitrogen dioxide, sulphur dioxide, ammonia, xylene, benzene and toluene.

Duplicate experiments with the addition of dust (iron ore) to rock surfaces.

After exposure rock samples (background surface and engraved surface) analysed for physical, mineralogical and chemical changes.

Duplicate experiments conducted with the addition of iron ore dust to the rock sample prior to the sample undergoing the accelerated weathering and aging.

Each test exposed six rock samples (three background samples plus three engraved rocks) to a prescribed range of pollutants. It should be noted that these were not engravings from the Burrup but were engravings made in the laboratory.

4.1.3. Key Study Results and Findings

There were no changes to the rock surface colour from pollutant concentrations likely to be experienced at the rock art locations.

4.2. Dust Deposition

Current understanding of rock interface chemistry suggests that dust deposition may play a role in rock surface weathering mechanisms.

The deposition processes and composition of deposited dust in the region was monitored through the use of micro-topographically replicated surfaces used to collect airborne dust.

The study was designed to characterise the dust that actually settles on rock surfaces rather than all airborne dust available for settling.

4.2.1. Study Objectives

The objectives of this component of the study were to:

- characterise (by chemical and mineralogical analysis) the dust that settles on rock surfaces
- establish the source of dust settling on rock surfaces
- monitor dust deposition processes and composition of deposited dust on the rock surfaces.

4.2.2. Study Approach

Sampling Locations:

3 sites – Dolphin Island, Burrup Rd, King Bay South

Monitoring Timeframe and Sampling Period:

- first tile exposure period 3 months; dust collected at the conclusion of the three month period
- second tile exposure period 12 months; dust collected at 6 month intervals.

Sampling Method:

- four synthetic rock tiles (micro-topographically replicates surfaces of typical engraved rocks) were mounted onto aluminium backing and erected onto an exposure rack at each sample site
- both active and passive techniques were utilised to collect the dust:

- active - a known volume of air is pumped through a filter for a defined period of time
- passive - collects only the particulates which have fallen and settled on a known surface area over a defined period of time

- at end of sampling period, the small amount of dust that has settled on the rock tiles was measured and removed
- the removed dust was subsequently analysed through a number of advanced techniques including x-ray diffraction analysis and inductively coupled plasma (ICP) spectrometry.

4.2.3. Key Study Results and Findings

Other studies (referenced within CSIRO 2007) found that dust deposition rates in the area are extremely low. In the long term (eg over a year) the natural environment leaves levels of dust on unsheltered rock surfaces that are at the limits of detection.

Dust collected from protected surfaces at the southern rock art sites on the Burrup (closer to industrial activity) is consistent with that of iron ore dust.

Dust collected from rock art surfaces at the northern sites (far from industrial activity) is consistent with windblown soil and sea salt.

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5. Study 4 - Microbiological Diversity

5.1.1. Study Objectives

This study (Murdoch University 2008) aimed to assess the microbiology of rock surfaces on the Burrup Peninsula with a view to monitor the microbiological difference (if any) of rock art sites. The microbiological assessment was undertaken by characterising the gross number and diversity of microorganisms on rock surfaces over a four-year sampling period (2004-2007) at five sites close to industrial emission sources, and at two sites distant from industrial emission sources.

5.1.2. Study Approach

Seven sites were selected for study:

- five southern sites close to the industrial emission sources - Woodside East, Burrup Road, Water Tanks, Deep Gorge and King Bay
- two northern sites distant from the industrial emission sources – Dolphin Island and Gidley Island
- 50 samples in total
- over a four year period (2004 – 2007).

Samples were collected from rock surfaces using sterile swabs (moistened with sterile water) and sterile filter paper discs (moistened with either sterile water, saline, isotonic buffered solution or media).

Sampled areas were photographed and described for location of sample sites for return visits.

Microscopic rock samples were collected aseptically from the rock surface at each site for direct sampling for enrichment cultures.

Samples were stored at four degrees Celsius until used for isolation and counting of bacteria.

In addition, in 2005 samples were collected from shaded and exposed sites.

5.1.3. Key Study Results

During the sampling period all seven sites had rock surfaces with similar very low populations of cultivable bacteria, usually less than ten viable bacteria per square centimetre. In addition, all sample sites appeared to have similar broad types of diverse bacteria and low numbers of fungi.

Lichens were never observed to have colonised the rock art. Lichens were observed to be relatively diverse and abundant near Site one on Dolphin Island, but were relatively rare at the six other monitoring sites and there appeared to be no relationship between presence of lichens and proximity to sources of industrial emissions.

There were no evident differences in the gross number and broad diversity of microorganisms associated with samples collected from sites close to and distant from industrial emissions on the Burrup Peninsula.

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6. Study 5 - Colour Change and Spectral Mineralogy

This Section summarises the outcomes of two closely related studies by CSIRO (2008b), specifically relating to colour change (**Section 6.1** of this report) and spectral mineralogy (**Section 6.2**).

6.1. Colour Change

A key issue of concern is the potential for colour change on the rock art. The study attempted to establish whether evidence of changes in the colour and contrast of images is measurable. Selected petroglyphs were monitored annually over four years with a technique known as reflectance spectroscopy, to provide information about the colour and mineralogy. This provides a numerical, objective record of the colour at points within selected petroglyphs and the background rock surface, which may be referred to at any stage in the future and evaluated for any evidence of colour change.

6.1.1. Study Objectives

The objectives of the study were to:

- assess whether there is a loss of colour contrast between rock art and adjacent rock surfaces
- assess if any colour change is occurring at a rate greater than that due to natural weathering
- establish a scientifically valid baseline for future assessments.

6.1.2. Study Approach

There were seven monitoring sites in total:

- five southern sites close to the industrial emission sources: Woodside East, Burrup Road, Water Tanks, Deep Gorge and King Bay
- two northern sites distant from the industrial emission sources: Dolphin Island and Gidley Island.

Monitoring was conducted over a four year period from 2004 to 2007, with the possibility of extension following review of initial 4 year monitoring results.

Monitoring was conducted through the use of a portable spectrophotometer, with natural light being excluded using a compressible collar. The measuring head had a diameter of 4mm, which allows for measurement of contrast between engravings and surrounding rock faces. The contrast in colour between engravings and adjacent rock faces was measured in terms of Delta E, the standard CIE colour difference method.

At each sample site three points on the petroglyph and three adjacent points on the rock surface was monitored. Each point was sampled an average of 7 readings, totaling 42 readings per sample site.

From 2005, 21 readings were taken at each sample point (3 times the originally intended 7 measurements) to reduce sample variance introduced by surface inhomogeneity, roughness, or systematic error.

Digital photography with a macro lens was used to relocate the instrument to within a millimetre.

The sampling period was annually, due to only small changes expected.

6.1.3. Study Results

Site averaged colour change values at the southern sites (Sites 4 to 8) were not consistently different to those at the northern control sites (Sites 1 and 2), with two slightly higher, two slightly lower and one comparable to the controls. This indicates that there was no consistent perceptible increase in colour change over the 2004 to 2007 period.

The colour measurements collected thus far may be used as a baseline measurement against which to compare future measurements in the short or long term and are a valuable and independent evaluation of changes in rock surface colouration on the Burrup Peninsula.

6.2. Spectral Mineralogy

Each of the measurement points evaluated for colour change was also characterised with spectral mineralogy to evaluate whether changes in mineralogy are observed on rock surfaces. Reflectance spectroscopy is a technique that provides information about the chemistry of a mineral from its reflected light.

6.2.1. Study Objectives

The study objectives were to:

- characterise and compare the mineralogy of the surface of the rock art and the surrounding undisturbed background rocks
- monitor any mineralogical changes in the engraved rock surfaces.

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6.2.2. Study Approach

The monitoring locations were the same as for the colour change study and over the same timeframe (**Section 6.1.2** of this summary report).

Mineral analysis was conducted through the technique of reflectance spectroscopy (the analysis of reflected light). Analysis and monitoring was conducted through use of a field spectrometer. At each sample site three points on the petroglyph and three adjacent points on the rock surface are monitored. Each point is sampled an average of 7 readings, totalling 42 readings per sample site (same sampling locations as those used for colour change monitoring study).

The sampling period was also annual, due to only small changes expected.

6.2.3. Study Results

For the spectral mineralogy study, the spectra for engravings were different to those measured for background. Also for the same spot at a site, the engravings contained less moisture than the corresponding background rock. For the large majority of the spots, mineralogically related absorptions were unchanged from 2004 to 2007 and only brightness varied from year to year: brightness decreases with increasing moisture.

However, some small changes were noted at two locations. Site 2 Spot 1 background (control northern Site), a small increase in the amount of iron oxides was detected and on the same site for Spot 2 background (control northern Site), a modest increase in the amount of gibbsite was detected. At Site 7 Spot 3 Background (southern Site), a small decrease in the amount of iron oxides was also detected. These small changes affected only 3 points out of the 42 points from all the sites studied. It should also be noted that Site 2, where two of the changes were detected, is the furthest from industrial activities.

No overall changes, for all engraving and background, at a site were observed. These small variations are local and correspond to natural mineralogical variations.

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7. References

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8. Abbreviations and Units

8.1. Abbreviations

BTEX	Benzene, toluene, ethylbenzene and xylene
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DoIR	(Western Australia) Department of Industry and Resources
DME	Dimethyl ether
DSD	(Western Australia) Department of State Development
HI	Hamersley Iron
LNG	Liquified natural gas
LPG	Liquified petroleum gas
Mtpa	Million tonnes per annum
NH_3	Ammonia
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides
OTP	Onshore treatment plant
PM_{10}	Airborne particulate matter less than 10 microns in diameter
SKM	Sinclair Knight Merz Pty Ltd
SO_2	Sulphur dioxide
TAPM	The Air Pollution Model
TSP	Total suspended Particles
WA	Western Australia

8.2. Units

kg	Kilograms
meq m^{-2} $year^{-1}$	Milliequivalents per square metre per year
mg m^{-2} day^{-1}	Milligrams per square metre per day
ppb	Parts per billion