BLACK RANGE
MINERALS

SYERSTON NICKEL COBALT PROJECT

ENVIRONMENTAL IMPACT STATEMENT

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ResourceStrategies

ENVIRONMENTAL IMPACT STATEMENT

VOLUME 2

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Black Range Minerals Ltd

ASSESSMENT OF AIR QUALITY FOR THE SYERSTON NICKEL COBALT PROJECT NEAR CONDOBOLIN, NSW

Newcastle,
August 2000

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1 INTRODUCTION

Black Range Minerals (Black Range) proposes to mine an average of 2 million tonnes per annum (Mtpa) of nickel cobalt laterite ore and establish a nickel and cobalt extraction plant at Syerston, 45 km northeast of Condobolin and 80 km northwest of Parkes in the Central West of New South Wales. Up to 42,000 tpa of nickel cobalt sulphide or an average of approximately 20 000 tpa of metal product would be produced for sale to international markets with maximum production of approximately 20 000 tpa of nickel and 5 000 tpa of cobalt.

The Project area is sparsely populated grazing and farming country, typical of the Western Plains of NSW.

In addition to the proposed mine site, Black Range proposes a number of components which when combined make up the Syerston Nickel Cobalt Project (the Project). In summary, the Project would involve:

- the mine site including ore processing, acid, power and steam plants, industrial gas and water treatment plants, open pit mining areas and mine waste disposal facilities (waste emplacements, tailings dams and evaporation ponds);
- a raw water supply borefield some 60 km to the south of the mine site;
- a water supply pipeline from the borefield to the mine site;
- a natural gas pipeline from the existing Sydney-Moomba gas-line located approximately 80 km south south-west of the mine site;
- quarrying, crushing and transport of limestone from a quarry approximately 20 km south-east of the mine site;
- a rail siding on the Bogan Gate-Tottenham Railway approximately 25 km to the south-east of the mine site; and
- road and access upgrades and construction of a road bypass.

An Environmental Impact Statement (EIS) for the proposed Project is required under the NSW Environmental Planning and Assessment Act (1979). The Project has mineral resources adequate for a mine life of over thirty years. In accordance with regulatory requirements, the EIS assesses the potential environmental impacts of the Project for a term of 21 years. This report has been prepared as supporting information for the EIS. It is an assessment of the potential air quality impacts of the above Project components for the EIS term. The assessment has been prepared in accordance with the Director General Requirements for the EIS.

Existing air quality and meteorology in the Project area is discussed in Section 2. A brief description of the proposal is given in Section 3. The description includes main aspects of construction, mining of the ore deposit by open cut methods, its handling and processing as well as the process of recovering nickel and cobalt metal. The associated extraction and handling of limestone material is also outlined.

The potential for generation of atmospheric pollutants and the proposed air quality safeguards are then outlined. The second part of Section 3 identifies potential emissions during normal plant operations, considers upset conditions and finally addresses emissions of fugitive dust.

Regulatory limits for the levels of particulate matter and atmospheric gases in the ambient air at locations outside the Project site are introduced in Section 4. Air quality goals are defined for the deposition and concentration of particulate matter and concentration of atmospheric gases including sulphur dioxide, nitrogen oxides and hydrogen sulphide.

The methodology of dispersion modelling of point source emissions is introduced in Section 5. The section also provides details of the input data including both the emission and meteorological data files and presents the results of the modelling estimates for each of the main pollutant types.

Dispersion modelling of particulate matter released as a result of mining and handling ore at the Project site is included in Section 6.

Criteria for the selection of representative years for inclusion in the modelling are given and inventories of dust emissions for the selected years are presented first. The results of dispersion modelling are presented next. Long-term rates of dust deposition predicted to result from the operation are given and related to amenity-based criteria which were specified by the EPA. The predictions are shown in a series of isopleths superimposed on the Project site and the impact is assessed for a variety of receptors and land uses including nearby residences.

Predictions of long-term concentrations of total suspended particulates in the ambient air and the impact assessment of long-term concentrations are presented in the last part of Section 6.

Section 7 is structured in a similar manner to Section 6 and is concerned with emissions of particulate matter from mining and crushing activities at the limestone quarry.

The main findings of the study are summarised and the conclusions are presented in Section 8. A list of references and attachments (A.1 to A.6) complete the report.

2 EXISTING METEOROLOGY AND AIR QUALITY

2.1 Meteorology of the Project Area

The Project site lies within a region which is located between the belts of the subtropical highs and the zone of mid-latitude westerlies. In summer, synoptic highs dominate the climate. Low pressure systems pass at regular intervals bringing milder temperatures and southerly winds.

In winter, the main influence on climatic conditions is from the mid-latitude westerlies. The presence of high pressure systems is interrupted by the passage of cold fronts which bring low temperatures and precipitation to the region.

The nearest meteorological station which is operated on behalf of the Bureau of Meteorology is situated at Condobolin. Standard observations include spot readings of wind speed and wind direction which are taken twice a day at 9 a.m and 3 p.m.

A continuously recording meteorological station was installed at the Project site in September 1998. The station is equipped with sensitive wind sensors and a range of other instruments which provides records of air temperature and relative humidity, solar radiation and rainfall at the site. The station is controlled by an electronic datalogger.

The recorded data were downloaded and processed monthly. Monthly wind rose diagrams and a summary of daily maxima and minima were then prepared. Monthly data checks were carried out to ensure that the sensors and the data logger were performing within specifications. A programme of maintenance and calibration was implemented.

Difficulties with the power supply for the meteorological station were experienced between March and August 1999. Because of a remote location of the station, data losses occurred during this period of time. The station returned to full operation in September 1999. Records from a similar installation located at Peak Hill approximately 70 km to the east of the Project site was used to supplement the data during March to August 1999. Comparisons between the records which were simultaneously collected at both locations at times prior to March 1999 and after August 1999 confirmed that there were no major differences between the main wind patterns at the two locations.

Seasonal and annual wind roses for the most recent period of 12 months from May 1999 to April 2000 are presented in Attachment A.1. The wind roses show the frequencies of hourly wind speeds and directions recorded each month at night (00h00 to 06h00), in the morning (06h00 to 12h00), in the afternoon (12h00 to 18h00) and in the evening (18h00 to 24h00).

The summer season, which was defined in the diagrams as an interval of 6 months from October 1999 to March 2000 was associated with two main types of winds. North to northeasterly winds were most frequent during the daytime as well as overall. Southwesterly winds were also common during the afternoon and in the evening.

Southeasterly and west to northwesterly winds were least frequent. Easterlies developed at various times during the day on a few occasions.

The winter season (April to September inclusive) was associated with an increased presence of winds from the southeastern quadrant and the south. North to northeasterly winds continued to be present but at a reduced level. Southwesterlies were mostly evident only in the afternoon. The annual wind rose reflected the seasonal as well as diurnal trends which were identified above. The three prevailing wind directions were from the northeast, south to southeast and southwest sectors.

The main trends in the wind records were in a general agreement with the long term 9 a.m and 3 p.m records from the Condobolin agricultural research station.

2.2 Existing Air Quality

2.2.1 Particulate matter

Dust Deposition

A monitoring programme of dust deposition rates was established at the Project site in September 1997. The purpose of the monitoring was to characterise the existing air quality in terms of atmospheric dust prior to the construction of the mine and processing plant. Atmospheric dust is currently generated in the project area by agriculture and vehicular traffic on predominantly unpaved roads. The action of strong winds on dry, barren areas may also result in the generation of airborne dust at times.

Five dust deposition gauges were installed to determine monthly rates of dustfall at locations shown in Figure 2.1. All 5 sites are located within the mining lease application (MLA) boundaries. The monitoring sites were selected to be representative of the general area which is an open and flat countryside used mainly for grazing and cropping.

Deposition gauges were maintained over a period of approximately 30 days, collected and sent to the laboratory for analysis. The mass of dried insoluble solids and combustible matter were determined for each sample. Most samples which were collected at monitoring sites FD-2 and FD-3 contained deposits of bird droppings and had to be excluded from the database. Sites FD-1, FD-4 and FD-5 were located in areas not frequented by birds and remained virtually free of contamination by bird droppings. Modifications to the bird protective rings at sites FD-2 and FD-3 were carried out in May 2000. The initial results indicate improved data recovery rates at both sites.

Site FD-1 was the only site which recorded contamination of 2 samples out of a total of 32 samples. The results for sites FD-1, FD-4 and FD-5 are summarised in Table 2-1. The table contains mean annual rates of dust deposition (insoluble solids), standard deviations from the mean, mean ash fractions remaining in the sample after ignition, and the number of valid measurements at each monitoring site.

Table 2.1

Mean dust deposition rates recorded at the Syerston Project site from September 1997 to May 2000

Site	Deposition Rate (g/m^2/month)				No. of Measurements
	Water Insoluble		Ash Fraction		
	Mean	Std. Dev.	Mean	Std. Dev.	
FD-1	1.05	(0.86)	62%	(19.7%)	30
FD-4	1.01	(0.85)	69%	(21.3%)	32
FD-5	1.35	(1.78)	64%	(22.7%)	32

The mean deposition rates over a period of 32 months ranged from 1.01 g/m^2/month at Site FD-4 to 1.35 g/m^2/month at site FD-5. The standard deviations from the mean ranged from about 82 to 132 per cent of the mean value. The narrow range of recorded values at FD-1, FD-4 and FD-5 confirmed the representativeness of the selected sites for the monitoring of existing dust levels in the general area.

The mean fractions of ash remaining in the samples after organic material was removed by ignition were between 62 and 69 per cent. The ash fractions indicated that although organic material of mainly plant and insect origin was a component of the recorded results, the organic content was well within the normal range.

Concentrations of TSP/PM_{10}

There are no records of concentrations of total suspended particulates (TSP) and particles with a diameter less than 10 microns (PM_{10}) in the ambient air at Syerston. Given the recorded low levels of dust deposition, the concentrations of TSP/PM_{10} are also expected to be correspondingly low. Mean annual TSP concentrations of not more than 20 to 30 micrograms/m^3 are normally found in areas similar to the area which includes the Project site. PM_{10} concentrations are then generally less than a half of the TSP concentrations.

2.2.2 Atmospheric gases

Syerston is situated in a rural environment with no significant industrial installations found near the Project site. Road and rail traffic represent only a minor source of emissions of atmospheric gases such as nitrogen and sulphur oxides, hydrocarbons and carbon monoxide. As a result, the existing levels of oxides of sulphur and nitrogen and the criteria air pollutants of gaseous origin are expected to be low. Particulate matter remains the main component of the airborne material in the ambient air.

3 DESCRIPTION OF THE PROPOSAL AND ATMOSPHERIC EMISSIONS

3.1 Outline of Proposal

A detailed description of the proposed development is given in the main body of the EIS. The main elements of the proposal with regards to atmospheric emissions can be identified as follows

- construction period,
- mining of the ore deposit,
- extraction of nickel and cobalt sulphide and metal products, and
- offsite mining of limestone.

3.1.1 Construction

The on-site construction period will be approximately 2 years in duration. The initial works will include the construction of a temporary workforce camp and site infrastructure followed by general construction of the plant and open cut mine. Initial tailings storages, evaporative storages and evaporation surge dam will also be constructed commencing from approximately month 9. One fleet will be working on one facility at a time starting with the tailings storage facility (TSF). The construction of the TSF will take about 6 months and will be followed by the construction of evaporation storages (6 months) and finally the evaporation surge dam (3 months).

3.1.2 Mining of ore deposit

Mining will be carried out by conventional open cut methods and be contained within an area of 2 km (north-south) by 3 kms (west-east). Selective mining will be carried out on 2 to 4 metre benches using 100 tonne backhoe excavators loading 86 tonne off-highway rear dump trucks. It is not anticipated that blasting will be required.

High-grade pit areas will be mined initially and lower grade ore will be stockpiled adjacent to and on the ROM pad. Small initial pit areas will be progressively cut back into fewer larger pit areas as the mine life progresses.

Primary ore blending will be achieved by selective ore production from four pit areas together with dumping into and reclaiming from two 100,000 tonne blending stockpiles on the ROM pad to maintain a consistent ore feed grade.

3.1.3 Process plant

Process Description

Following benefication (ie. ore preparation and removal of siliceous reject material), the process plant will treat the ore to produce saleable nickel cobalt sulphide precipitate or nickel and cobalt cathode. The process plant consists of the following unit operations: ore preparation, acid leaching, CCD thickening and tailings neutralisation, solution neutralisation, sulphide precipitation, sulphide leaching and impurity removal, solvent extraction, electrowinning and support processes.

Ore Preparation

Run-of-mine ore will be delivered to a blending pad, from which it will be retrieved by front end loader and fed through a toothed roll sizer to a slurry mill. The mill will discharge onto a screen separating at nominally 1 mm, the oversize being rejected and the undersize pumped to a storage vessel ahead of the pressure leach stage.

Pressure Leaching

Ore leaching will be conducted in a single titanium-lined autoclave. Leaching will be effected by sulphuric acid injected into the autoclave.

The ore slurry will be preheated by means of flash and live steam prior to being fed to the autoclave. Following leaching, the slurry will be discharged from the autoclave to a series of flash vessels, from which flashed steam will be delivered to the preheaters. The slurry is cooled in the flash vessels for further processing.

CCD Washing

The cooled autoclave discharge slurry will be washed with recycled barren solution and process water in a multi-stage CCD washing thickener circuit. The leach residue will be neutralised with limestone slurry and pumped to the tailings dam.

Solution Neutralisation

The product solution from the CCD washing circuit will be neutralised with limestone slurry. The neutral slurry will then be thickened, the underflow recycled to the CCD circuit and the overflow filtered and stored ahead of the sulphide precipitation circuit.

Sulphide Precipitation and Grinding

The filtered neutral solution will be heated and contacted with hydrogen sulphide gas to effect the precipitation of mixed nickel and cobalt sulphides. The product slurry will be thickened, the barren overflow neutralised with limestone slurry and recycled as a component of the wash water stream in the CCD circuit. The sulphide product will form an intermediate product, or will pass to a sulphide mill to reduce the particle size suitable for sulphide leaching.

Sulphide Leach and Impurity Removal

The product from the sulphide precipitation and grinding circuit will be processed in a single autoclave. Oxygen will be injected into the autoclave to effect the oxidation of the sulphides and the dissolution of the nickel and cobalt as sulphates.

Solvent Extraction

Nickel and cobalt will be separated into nickel and cobalt by means of sequential solvent extraction processes to produce rich electrolyte streams for downstream metal recovery.

Nickel Electrowinning

The nickel electrolyte will be drawn from storage and heated with steam in a heat exchanger before entering the electrowinning cells. Nickel metal cathode will be stripped automatically and weighed and packaged on pallets for shipment.

Cobalt Electrowinning

The cobalt electrolyte will be drawn from storage and heated with steam in a heat exchanger before entering the electrowinning cells.

The cathodes will be stripped and the cobalt metal fed through a toothed roll crusher before vacuum degassing, weighing and packaging in drums for shipment.

Power Generation

Power will be generated on site by two 20 MW gas turbine generators each fitted with a heat recovery and steam generation (HRSG) unit. A 10 MW steam turbine generator will also be provided together with an auxiliary boiler. Emergency electrical supply will be provided by 3 x 1 MVA diesel generators.

Sulphuric Acid

Sulphuric acid will be produced on site by the combustion of elemental sulphur to form sulphur dioxide, followed by double contact catalytic conversion to sulphur trioxide and absorption in water to produce 98.5% pure sulphuric acid. The acid will be used in the ore pressure leaching process.

The process is exothermic, and the heat of reaction will be used to produce superheated steam for use in the process plant.

Hydrogen

Hydrogen will be produced by the reforming reaction between natural gas and steam using a nickel based catalyst. The purified hydrogen will be used in the production of hydrogen sulphide gas.

Hydrogen Sulphide

Hydrogen sulphide gas will be produced by reacting hydrogen gas with molten sulphur. Sulphur will be circulated through a vertical packed column reactor and hydrogen injected at the bottom of the vessel. Pure hydrogen sulphide will be withdrawn from the top, cooled, and delivered to the sulphide precipitation circuit.

Oxygen/Nitrogen

An air separation unit will be used to produce oxygen for the sulphide leaching process and nitrogen for plant purge uses.

Caustic Soda and Magnesium Oxide

Caustic soda and magnesium oxide will be imported and used for pH control in the ore processing. Caustic soda would also be used in the water treatment plant.

Sulphur

Sulphur for the production of sulphuric acid will be delivered by trucks after collection from the rail siding. Trucks will discharge sulphur into a hopper from which conveyors will transport the material either directly to the sulphuric acid plant or to a stockpile. Dust suppressants will be sprayed on the stockpile, the hoppers and all transfer points to minimise dust emissions.

3.1.4 Limestone quarry

Crushed limestone will be delivered to the site from a quarry located at the Westella deposit approximately 20 km to the south-east. Limestone will be mined by a conventional method.

The topsoil will be stripped in advance of the mining operation, and stockpiled for later use in site rehabilitation.

The uncovered limestone deposit will initially be mined by drill and blast techniques, engineered to maximise fragmentation of the all shot limestone material. During initial establishment of the quarry, blast volumes in the order of 8,000 BCM are expected. As the mine increases in size and is less physically constrained, a single blast of 17,000 BCM each month may be required to meet the limestone high grade feed requirements. Single blasts in the order of 30,000 BCM are achievable at a fully developed mine.

The blasted material will be free dug with a Caterpillar 990 style front-end loader (FEL), and campaign transported to the crushing facility or waste dump using 40 tonne articulated dump trucks.

The ROM material will be FEL fed into a screen to remove the predicted 38% - 90mm material bypass materials. The 68% +90mm oversize material will be fed by conveyor directly into a 200 tonne/hour throughput jaw crusher.

The FEL will be used to manage both the crusher feed, crushed and screened material stockpiling and loading of road haulage units.

A secondary impact crusher will be used to reduce the size to 30 mm. Fogging (water spray) will be applied to minimise dust generation during the crushing and screening process.

Waste and low grade material will be managed using redundant capacity in the articulated dump trucks and FEL. A dozer will be used for shaping of topsoil, waste and low grade material dumps as required.

Benches, ramps and haul roads will be formed and maintained using a tracked dozer and a suitable motor grader.

Crushed limestone material will be transported to the Project site in covered side tipping road trains of 50 tonne payload. The haulage fleet will operate 260 days/annum on 2 x 12 hour shifts/day and be capable of a maximum delivering rate of approx. 2,000 tonnes/day to the Syerston crushed limestone receival facility.

3.2 Atmospheric Emissions and Controls

The feasibility study included an Environmental Management Statement (EMS) prepared for the Project (SNC Lavalin, 2000) which contains details of the projected emissions from the plant and the proposed emission controls and safeguards including emission monitoring. The air quality assessment in this report is based on the information provided in the EMS.

3.2.1 Gaseous emissions and controls - normal plant operations

The gaseous emissions from the plant will consist of:

- Low pressure steam from acid pressure leach letdown train scrubber;
- Mist and water vapour from the water cooling tower;
- Sulphur dioxide from the sulphuric acid plant and the hydrogen sulphide flare;
- Oxides of nitrogen from the power plant gas turbines and/or boilers (depending on which is operating) and intermittent emissions of nitric oxide from dissolution of cobalt using nitric acid;
- Oxygen, hydrogen and water vapour evolved in the nickel and cobalt electrowinning plants;
- Carbon dioxide from the neutralisation circuits which use limestone, power production and the hydrogen plant;
- Trace emissions of hydrogen sulphide from the hydrogen sulphide plant and process circuits;
- Process steam; and
- Laboratory sample preparation fumes.

Emissions of hydrogen sulphide will be flared prior to discharge. Trace atmospheric emissions of this gas may occur during the normal course of operations at infrequent intervals, or during plant start-up or plant shut-down. Under normal operating conditions there will be a continuous stream of hydrogen sulphide containing gas being directed to the hydrogen sulphide flare which is a bleed stream from the sulphide precipitation autoclave after primary scrubbing by reacting with CCD overflow solution.

This stream will be directed via the No.1 flare knock out drum to the hydrogen sulphide flare provided for the burning of the residual hydrogen sulphide. The calorific value of this stream is low (about 4 MJ/m^3) and natural gas will be injected into this stream to assist combustion. The hydrogen sulphide flare will combust the hydrogen sulphide to form sulphur dioxide.

The exhaust gas from the gas turbines at the power plant is expected to contain 0.07 grams of oxides of nitrogen or less per cubic metre of exhaust gas. An average content of 6 mg SO_2/m^3 in the Moomba-Sydney gas pipeline was used in the EMS to calculate an emission rate of 0.04 grams of SO_2 per second.

The estimated carbon dioxide emissions from the whole project are expected to be in the order of 300,000 tpa. The expected emissions from the plant during normal operations are summarised in Table 3.1.

Table 3.1

Atmospheric emission characterisation point sources - normal operations

Source	Acid High Pressure Leach Scrubber	CCD Thickeners	Tailings Neutralisation Vent Stack	Leach Liquor Neutralisation Tank Vents	Vent from Extraction Fan over Sulphide filter	Sulphide Leach Vent
Description	Uncondensed steam	Water Vapour	Water Vapour with Carbon Dioxide	CO_2 evolved from Neutralisation and Water Vapour	Air Combined with trace quantities of H_2S	Oxygen and Water Vapour (3)
Stack height (m)	40	9	16	15	15	15
Emission Volume (Am^3/hr)	68,000	60,000	7,400	10,000	18,000	1,430
Emission Temperature (°C)	99	82	85	70	50	100
Sulphur Dioxide (g/s)	-	-	-	-	(2)	-
Oxides of Nitrogen (g/s)	-	-	-	-	-	-
Water Vapour (kg/s)	11.1	9.7	0.75	0.63	-	0.4
Carbon Dioxide (kg/s)	-	-	1.22	2.83	-	-

Table 3.1 (Continued)

Atmospheric emission characterisation point sources - normal operations

Source	Nitric Vent Fan	Nickel Electrowinning Tankhouse Vents	Sulphuric Acid Plant	Limestone Wet Scrubber	Flare Stack	Hydrogen Reformer Stack
Description	Air and Trace Oxides of Nitrogen	Water Vapour, Oxygen and Hydrogen (4)	Residual gas ex.acid production	Water Vapour and Water Mist	Water Vapour and Sulphur Dioxide	Combustion Gases
Stack height (m)	10	10	80	20	80	36
Emission Volume (Am^3/hr)	1,000	9,100	78,000	24,000	6,000	7,800
Emission Temperature (°C)	25	55	75	25	700-750	204
Sulphur Dioxide (g/s)	0		25.7	-	21.3	-
Oxides of Nitrogen (g/s)	7.0(5)	-	-	-	0.11	0.12
Water Vapour (kg/s)	0.1	1.6	-	0.55		0.20
Carbon Dioxide (kg/s)	-	-	-	-	0.0007	0.48

Table 3.1 (Continued)

Atmospheric emission characterisation point sources - normal operations

Source	Power Plant HRSG	Main Plant Cooling Tower
Description	Combustion Gases	Water Vapour
Stack Height (m)	25	10
Emission Volume (Am^3/hr)	136,000	55,000
Emission Temperature (°C)	160	27
Sulphur Dioxide (g/s)	0.11	-
Oxides of Nitrogen $^{(1)}$ g/s	2.6	-
Water Vapour (kg/s)	3.7	11.6
Carbon Dioxide (kg/s)	4.5	-

Source: SNC 2000

Notes: 1. Oxides of nitrogen expressed as nitrogen dioxide
2. Hydrogen Sulphide emission expected to be 0.0003 g/s
3. Vented gas will contain 1.0 kg/h oxygen and 0.4 kg/h nitrogen
4. Exit gas will contain 4.4% oxygen and 0.1% hydrogen
5. Once a week for one to two days

Emission Monitoring

A routine gaseous emission monitoring program will be established once steady state conditions prevail in the Syerston processing plant. This program will be designed in consultation with the relevant authorities and is likely to include:

- Sulphur dioxide from the sulphuric acid plant - monitoring of the sulphur dioxide concentration in the gas from the stack;
- Gas Turbine exhaust monitoring for oxides of nitrogen;
- Oxides of nitrogen in the hydrogen plant emissions;
- Acid pressure leach scrubber stack;
- Nitric acid wash tank vent stack for oxides of nitrogen.

3.2.2 Potential gaseous emissions and controls - upset conditions

Potential upset conditions that may occur within the plant are as follows:

Failure of Natural Gas Supply

Under this scenario the gas turbines would be shut down and the stand-by diesel emergency generators would be used to maintain essential power and the rest of the plant would be shut down. Total failure of the natural gas supply is unlikely. However, in the event of a failure there would be sufficient gas in the pipeline to enable an orderly shutdown of the plant, and maintenance of the H_2S flare pilots.

Sulphuric Acid Plant Start-up

During start-up of the sulphuric acid plant the emissions of sulphur dioxide will be greater than during normal operations. However, the increased emissions will be of short duration.

Hydrogen Sulphide Flare

Four potential occasional or upset conditions have been identified as possible in relation to the flaring of hydrogen sulphide containing gases. These four cases are:

- Depressurisation of the hydrogen sulphide plant prior to a planned shutdown. In this case the inventory of hydrogen sulphide gas held within the process is gradually let down prior to any maintenance being performed. During this time the hydrogen sulphide gas that would otherwise be consumed within process will be flared in a controlled fashion.

- A failure of the valve supplying hydrogen sulphide gas to the sulphide precipitation area. In this case, when the hydrogen sulphide gas normally consumed is prevented from entering the sulphide precipitation autoclave it is redirected to the hydrogen sulphide flare. This will occur only for a short time (less than two minutes while the hydrogen sulphide plant load is cut back). The hydrogen sulphide flare stack flare tip is designed to be a high efficiency burner. There are four pilot burners at the flare tip to prevent escape of unburnt gases.

- Fire relief of the hydrogen sulphide reactor with continuous vents from other parts of the process plant. The relief flow would consist primarily of sulphur vapour at 444°C.

- Fire relief of the sulphide precipitation autoclave. This would be a very rare event. This gas stream will consist mainly of steam with a small amount of hydrogen sulphide present.

The maximum expected emission rates for these upset scenarios are presented in Table 3.2. Each of the scenarios are described in the table. The potential impacts of upset conditions gaseous emissions are further assessed in the Preliminary Hazard and Risk Assessment for the project (SHE, 2000) attached to the EIS as Appendix B.

Table 3.2

Atmospheric emission characterisation
Point sources - upset conditions

Source	Flare gas resulting from a depressurisation of the hydrogen sulphide production facility during a shutdown	Upset within process - failure of supply valve to major H_2S user and diversion of full production flow to the flare	Fire relief of the Hydrogen Sulphide Reactor
Stack height (m)	80	80	80
Frequency	Once per annum	1 per 10 years	1 per 30 years (2)
Duration	30 mins	10 min	15 min
Emission Volume (Am^3/hr)	20,000	190,000	570,000
Emission Temperature (°C)	700-750	700-750	900-1000
Sulphur Dioxide (g/s)	160	1,570	3,800
Oxides of Nitrogen (g/s)(1)	0.86	8.5	25
Water Vapour (kg/s)	-	-	-
Carbon Dioxide (kg/s)	0.005	0.05	0.15
Carbon Monoxide (kg/s)	-	-	-

Table 3.2 (contd)

Atmospheric emission characterisation
Point sources - upset conditions

Combustion Gases		
Source	Fire relief of a Sulphuric Precipitation Autoclave	Test running of Emergency Generator Sets
Stack height (m)	80	3
Frequency	1 per 30 years (2)	Once every month for all three 1 MVA generator sets (3)
Duration	15 min	15 min
Emission Volume (Am^3/hr)	13,000	4,000
Emission Temperature (°C)	190°C	1,000°C
Sulphur Dioxide (g/s)	trace	-
Oxides of Nitrogen (g/s)	trace	trace
Water Vapour (kg/s)	1.65	0.1
Carbon Dioxide (kg/s)	-	0.21
Carbon Monoxide (kg/s)	-	trace

Source: SNC (2000)

Notes:
1. Oxides of nitrogen expressed as nitrogen dioxide.
2. This represents once in the project life and is an extremely unlikely occurrence.
3. Emission figures are for one generator, generators will be tested sequentially.

3.2.3 Fugitive dust emissions and controls

Fugitive dust would be the main component of air emissions from the mining component of the Project.

A range of air quality safeguards will be implemented to minimise the generation of atmospheric dust from the open cut operations. These safeguards will be based on current control techniques as recommended for open cut mining in New South Wales by the EPA. The main aspects of the controls can be summarised as follows.

During the construction period, watering of disturbed surfaces as well as access roads will be used to reduce dust emissions. Restricting the size of the surface area which would be disturbed at any given time is an effective approach to dust control and will be applied as often as possible.

Maintaining small total areas which are exposed to dust generation by wind erosion, regular watering of dusty surfaces, and watering and clear route marking of haul roads will be the main aspects of the air quality safeguards during the mining and handling of all ore, waste and limestone bulk materials.

The other aspects of dust control will include collection of fine dust from drilling, prevention of truck overloading and the resulting spillage of waste material and ore during loading and hauling, and regular maintenance of all haul roads. Watering and regular maintenance are expected to result in a control efficiency of at least 50 per cent.

The waste emplacement areas will be progressively reshaped and rehabilitated to minimise the potential for wind erosion.

The proposed air quality safeguards at the processing plant will be designed not only to minimise fugitive emissions to air but also to retain as much of the valuable ore as possible for further processing.

Water sprays will be used for dust suppression and the conveyors will incorporate wind covers as necessary.

Details of emission estimates for particulate matter from mining and handling of bulk materials are presented in Section 6, Section 7 and Attachments A.4 and A.5.

4 REGULATORY LIMITS

The EPA of NSW has set the assessment criteria for both particulate matter and atmospheric gases resulting from the construction and operation of the Project. The EPA requirements are reproduced in Attachment A.2.

4.1 Particulate Matter

In New South Wales, the EPA has adopted amenity based criteria for dust deposition expressed as annual means. The maximum acceptable increase in the mean annual dust deposition rate is 2 g/m^2/month in those areas in which the existing rate of dust deposition does not exceed 2 g/m^2/month. The criteria seek to limit the total dust deposition rate (the sum of the existing level and the increment due to a new development) to 4 g/m^2/month in suburban residential areas and to 5 g/m^2/month in rural, semi-rural and commercial and industrial areas.

The health effects of dust are related to the concentration of suspended particles in the air as distinct from dust fallout. The effects of inhaled dust are specifically related to the types of particles inhaled, the particles' sizes, the ability of the respiratory tract to capture and eliminate the particles and the reactivity of the particles with lung tissue.

The National Health and Medical Research Council of Australia (NHMRC) recommended annual concentration of 90 micrograms/m^3 as the maximum permissible level of total suspended particulates (TSP) in the air to protect public health in residential environments.

Prior to the introduction of the NEPM goal for PM$_{10}$ particles, the NSW EPA used air quality objectives which were based on USEPA standards for particles with aerodynamic diameters of less than 10 microns in size (PM$_{10}$). By contrast, total suspended particulates (TSP) range in size to 30 microns and possibly higher. USEPA objectives sought to limit the mean annual concentration of PM$_{10}$ in residential environments to 50 micrograms/m^3 and the highest 24 hour concentration to 150 micrograms/m^3.

Both these objectives have, however, been withdrawn in New South Wales. There is no current assessment criteria or goal which could be applied to emissions of TSP/PM$_{10}$ from a single development such as the proposed development for intervals shorter than one year.

In the context of regional air quality and as a goal for air quality in population centres of more than 25000 people, the NSW Action for Air set an interim goal of 50 micrograms/m^3 for

PM_{10} concentrations over both 24-hour and annual intervals. Action for Air is a 25 year plan which focuses specifically on the Greater Metropolitan Region of Sydney, the Illawarra and the Lower Hunter. However, as previously advised by the NSW EPA, this goal is not appropriate for establishing regulatory limits for one particular development (NSW EPA, 1999). Furthermore, there would be only approximately 30 occupied residences within a 5 km radius of the Project boundaries.

4.2 Atmospheric Gases

The list of criteria pollutants in Attachment A.2 contains air quality goals for oxides of sulphur and nitrogen which would form the main component of the emissions from the extraction plant at Syerston.

The goals correspond to NEPM values for both sulphur dioxide (SO_2) and nitrogen dioxide (NO_2). Ground level concentrations of SO_2 must thus be limited to a 1-hour maximum of 572 micrograms/m^3 (0.20 ppm), a 24-hour maximum of 229 micrograms/m^3 (0.08 ppm) and an annual mean of 57 micrograms/m^3 (0.02 ppm).

Similarly, ground level concentrations of NO_2 in the ambient air at locations outside the site boundary are not to exceed 246 micrograms/m^3 (0.12 ppm) over intervals of 1 hour and an annual mean of 61 micrograms/m^3 (0.03 ppm).

The documentation published by the National Environment Protection Council (NEPC,1998) includes an allowance for one exceedance day per year for the 1 hour standards for both SO_2 and NO_2 as well as for the 24 hour standard for SO_2.

The NSW EPA does not have specific ambient design criteria for atmospheric gases not listed in Attachment A.2. In their absence, the EPA recommended the use of the Victorian EPA criteria as a suitable basis for assessing the air emissions from the proposed development. For maximum ground level concentrations of hydrogen sulphide (H_2S) over intervals of 3 minutes (at a 99.9 percentile level), the Victorian design level is 0.1 ppb or 0.14 micrograms/m^3.

5 MODELLING AND ASSESSMENT OF POINT SOURCE GASEOUS EMISSIONS

5.1 Methodology

The point source emissions were used together with one year of meteorological data in an air dispersion model to obtain ground level concentrations of SO_2, NO_x and H_2S in the ambient air around the site. A standard Gaussian plume model (AUSPLUME) was applied for this purpose.

Ground level concentrations were calculated at each point of a receptor grid which covered an area of 20 km x 20 km. A step size of 500 m was used in the model. The meteorological data included both the winter (April to September) and the summer (October to March) seasons.

The ground level concentrations were calculated for intervals ranging from 3 minutes to 1 hour, 24 hours and a full year according to the averaging times for which air quality goals were defined in Section 4.2. The highest concentration values were then determined for each of the grid points. A computer plotting routine was used to draw an envelope of the highest concentrations. The computer plots were finally superimposed on a map of the area showing the Project site and its surroundings.

5.2 Input Data

5.2.1 Emission data

Information contained in Table 3.1 was used to develop emission data files for SO_2, NO_x and H_2S. Emission sources of SO_2 included the sulphuric acid plant, the power plant and the flare.

Emission sources of NO_x included the nitric vent fan and the hydrogen reformer stack as well as the power plant and the flare. Vent from the extraction fan over the sulphide filter was the source of H_2S emission. A summary of the emission data is given in Table 5.1. The locations of the modelled point sources are shown on Figure 5.0. Samples of the input files are included in Attachment A.3.

Table 5.1

A summary of point source emission data used in the modelling

Source

Sulphuric acid plant

Stack height = 80 m
Stack diameter = 1.17 m
Stack gas volume = 17.0 Nm^3/s
Stack gas temperature = 348°K

Emission rate of SO_2 = 25.7 g/s

Power plant

Stack height = 25 m
Stack diameter = 1.55 m
Stack gas volume = 23.8 Nm^3/s
Stack gas temperature = 433°K

Emission rate of SO_2 = 0.11 g/s
Emission rate of NO_x = 2.6 g/s

Hydrogen sulphide flare

Stack height = 80 m
Stack diameter = 0.5 m
Stack gas volume = 0.52 Nm^3/s
Stack gas temperature = 873°K

Emission rate of SO_2 = 21.3 g/s
Emission rate of NO_x = 0.11 g/s

Hydrogen reformer stack

Stack height = 36 m
Stack diameter = 0.43 m
Stack gas volume = 1.23 Nm^3/s
Stack gas temperature = 481°K
Emission rate of NO_x = 0.12 g/s

Nitric vent fan

Stack height = 10 m

Stack diameter = 0.15 m
Stack gas volume = 0.25 Nm^3/s
Stack gas temperature = 873°K

Emission rate of NO_x = 7.0 g/s
(limited to 1-2 days per week)

Vent from sulphide filter extraction fan

Stack height = 15 m
Stack diameter = 0.56 m
Stack gas volume = 4.2 Nm^3/s
Stack gas temperature = 323°K

Emission rate of H_2S = 0.0003 g/s

Note: Emission rates of NO_x are expressed as NO_2

Projected emission concentrations and Clean Air (Plant and Equipment) Regulation 1997

The projected continuous emissions of NO_x and H_2S as well as the emission of SO_2 from the sulphuric acid plant remain below the maximum concentrations which are specified in Clean Air (Plant and Equipment) Regulation 1997.

For sulphuric acid plants manufacturing sulphuric acid from elemental sulphur, the Regulation requires the emission concentration not to exceed 2.8 grams of SO_2 per cubic metre of the exhaust gas (Part 2, Table B). The projected emission concentration of SO_2 in Table 5.1 was approximately 1.5 g/m^3.

The same section of the Regulation sets a limit of 5 milligrams per cubic metre of exhaust gas to any emission of H_2S. The concentration of H_2S from the sulphide filter extraction fan in Table 5.1 is equivalent to 0.07 mg/m^3.

Various limits apply to emissions of NO_x depending on the process involved. For gas turbines with a capacity of 10 megawatts or more, Part 4, Table C of the Regulation specifies a limit of 0.07 grams of NO_2 per cubic metre. The projected emission concentration of NO_x in Table 5.1 is equivalent to 0.01 grams per m^3.

A limit of 2.0 g/m^3 applies to NO_2 emission from any process other than manufacture of glass. Emission concentrations of NO_x equal to 0.21 g/m^3 and 0.1 g/m^3 are expected in the exhaust gas from the flare and the hydrogen reformer stack respectively. NO_2 will constitute only a fraction of the total emission of NO_x from all the above sources of NO_x.

Intermittent emission of NO_x will be released from the nitric vent fan. The emission is expected to be restricted to 1 or 2 days a week. The composition of NO_x and thus the NO_2 equivalent concentration in the exhaust gas are not known at this stage. When all NO_x is expressed as NO_2, the concentration would be 28.0 g/m^3.

Further consultation with the EPA will thus be needed during the licence approval process to determine the actual concentration of NO_2 in a non-continuous emission and a possible introduction of further control measures to reduce the concentration as required.

5.2.2 Meteorological data

A minimum of one year of data is needed to include seasonal variations in the data base for use in dispersion modelling. As a result of the monitoring, 20 months of records were available for analysis and inclusion in the air quality modelling.

Meteorological data for use in the model were derived from the measurements at the Project site and Peak Hill meteorological stations which were collected during a period of 12 months from May 1999 to April 2000.

The basic recording interval was one hour and mean values of wind speed, wind direction, air temperature and solar radiation were used together with records of sigma theta (standard deviation of horizontal wind direction) to develop an input data file for application in the model.

A general description of the data and the main wind patterns were outlined in Section 2.1.

The USEPA guideline for modelling (USEPA, 1986) calls for the use of a minimum wind speed of 1.0 m/s for calculations of ground level concentrations over intervals of 24 hours and less in Gaussian plume models. The guideline was followed during the preparation of the meteorological data to avoid unrealistically high concentration values during intervals of near-calm winds.

The determination of stability classes was carried out using measurements of incoming solar radiation, wind speed and sigma theta. The latter was determined

as $\sigma_{\varnothing} = ((\sum\sigma_{\varnothing i}{}^{2}{}_{15\text{-}min}/4))^{0.5}$ from the recorded data.

Daytime calculations using solar radiation and wind speed were carried out for all hours with incoming solar radiation of, at least, 80 Wm-2. Sigma theta and wind speed were used for intervals with incoming solar radiation of less than 80 Wm-2. Scheme by Mitchell et al (1982) was applied for that purpose.

A summary of the stability determinations is given in Table 5.2.

Table 5.2

Frequencies (per cent) of atmospheric stability categories estimated for a 12-month period from May 1999 to April 2000

Atmospheric Stability Category					
Unstable		Neutral		Stable	
A	B	C	D	E	F
4.4	11.3	12.5	39.3	14.3	18.3

Mean values for Monin-Obukhov length were assigned to each stability category and used together with calculated hourly values of surface friction velocity to obtain estimates of mixing heights for unstable and neutral conditions.

A diskette with the meteorological input data file is available on request.

5.3 Modelling Results

5.3.1 Sulphur dioxide

Maximum ground level concentrations of sulphur dioxide were modelled for intervals of 1 hour, 24 hours and a full year. A contour map of the predicted highest 1-hour concentrations is shown in Figure 5.1.

The predicted values outside the boundary of the Project site and at all surrounding residences remained well below the NEPM goal of 572 micrograms/m^3.

A contour map of the predicted highest 24-hour concentrations is shown in Figure 5.2. Concentrations at all locations outside the site boundary were predicted to remain safely below the NEPM goal of 229 micrograms/m^3.

Similarly, the predicted mean annual concentrations in Figure 5.3 remained safely below the annual NEPM goal of 57 micrograms/m^3.

The above modelling estimates were obtained for emissions during normal plant operations. Possible short-term increases in the emission rate of SO_2 and their estimated frequency of occurrence and duration were listed in Table 3.2.

The frequencies ranged from one occurrence per year to one occurrence in 30 years. The estimated duration of the emission ranged from 10 to 30 minutes. The resulting transitional increments in the ground level concentrations of SO_2 from releases of that frequency and duration will not breach the NEPM goals.

5.3.2 Nitrogen oxides

Maximum ground level concentrations of nitrogen oxides were modelled for intervals of 1 hour and a full year. When a full conversion of NO_x to NO_2 at the point of release was modelled (all NO_x expressed as NO_2), the highest 1-hour concentration of NO_2 outside the plant site boundary exceeded the NEPM goal of 246 micrograms/m^3.

The main contributor to the predicted highest concentration of NO_x (expressed as NO_2) was the emission from the nitric vent fan. This emission is expected to take place only 1 to 2 days per week and will not consist of only NO_2 but other oxides of nitrogen as well. The ratio of NO_2 to NO_x in the NO_x emissions is not known at the present but is not expected to exceed or even reach 50 per cent from any of the emission sources.

Figure 5.4 shows the envelope of predicted maximum 1-hour concentrations of NO_2 for a ratio of NO_2 = 50% of NO_x. The predicted values at locations outside the site boundary meet the NEPM goal of 246 micrograms/m^3. Emission monitoring has been proposed for the main sources to confirm the fraction of NO_2 in the total emission of NO_x. Alternatively, Black Range advise that additional controls will be designed for the main source or sources of NO_2 to ensure that the concentrations of NO_2 in the ambient air outside the plant site remain with the NEPM goal for 1-hour maxima.

The conversion of NO_x to NO_2 increases over longer intervals of time and the annual concentrations of NO_2 in Figure 5.5 were obtained for a full conversion to NO_2. The resulting concentrations remained safely within the NEPM goal of 61 micrograms/m^3.

5.3.3 Hydrogen sulphide

Maximum ground level concentrations of H_2S were modelled for intervals of 3 minutes to enable a comparison with the Victorian design value of 0.14 micrograms/m^3. The modelling predictions are presented in Figure 5.6 and indicate safe levels at all locations outside the site boundaries.

5.4 Impact Assessment

The modelling predictions indicated that the plant will be capable of operating without breaching the NEPM goals for concentrations of SO_2 and NO_2 and the Victorian design concentration of H_2S in the ambient air at all locations outside the plant site boundaries.

6 MODELLING AND ASSESSMENT OF FUGITIVE DUST EMISSIONS - MINE

An outline of the proposed extraction of nickel and cobalt bearing ore and its handling was presented in Section 3.1.2. Further details are contained in the main volume of the EIS.

6.1 Methodology and Input Data

6.1.1 Dust emissions

Dust particles will be generated by a variety of operating equipment and range in size from minute particles in the submicron range to much heavier particles which settle rapidly not far away from the place of their origin.

The particles remaining in the air are carried by wind and dispersed by the action of the atmosphere. The weight of the particles and the uptake characteristics of the surface cause the particles to deposit on the surface at various distances from the operations under changing atmospheric conditions.

The rates of dust emissions were determined for individual extraction activities including loading and haulage of both the ore and the waste rock, emplacement of waste rock and handling and processing of both grades of ore at the processing plant. The dust emission factors which were used in the estimates are listed in Table A.4.1 in Attachment A4. Details of the dust emission inventories are also given in Attachment A.4 (Tables A.4.2 to A.4.5). Particle size distributions which were applied to the emissions are given together with the appropriate references in Table 6.1.

Table 6.1
Particle size distributions of dust emissions

Bulk materials handling
(AWMA, 1992) - p.136

	< 30 μ	< 15 μ	< 10 μ	< 2.5 μ
	0.74	0.48	0.35	0.11
normalised to	1.0	0.65		0.15

Wind erosion
(AWMA, 1992) - p.136

< 30 μ	< 15 μ	< 10 μ	< 2.5 μ
1.0	0.6	0.5	0.2

Haulage
(SPCC, 1986)

< 30 μ	< 15 μ		< 2.5 μ
1.0	0.59		0.06

Note: μ = micron

Four individual years of mining were selected for inclusion in the quantitative assessment. They included three years of operation (Years 5, 10 and 20) and one year of construction. The latter is presented as Year-1.

Emissions in Year-1 (Construction)

Construction of the mine, processing plant and all associated infrastructure will be carried out over a period of approximately 24 months. In terms of emissions of atmospheric particulates (dust), the most active period will be between months 9 and 20 when both the southern tailings storage facility (TSF) and the evaporation ponds will be constructed using materials extracted in-situ as well as from the pits.

Construction of the southern TSF cell will be carried out in months 9 to 15 and be followed by the construction of the evaporation ponds. The construction will include clearing, ripping and compacting of the base areas, trench excavation and the hauling, placing and compacting of selected mine overburden or borrow materials. The construction fleet will consist of excavators, scrapers and dozers, 20 t trucks, graders, front end loaders and water carts.

An emission inventory is presented in Table A.4.2 in Attachment A.4. Extraction and haulage of 1.185 Mtpa of waste rock from the pit area to either the western emplacement or the TSF area were estimated to result in an annualised emission of 406.1 tonnes. Excavation of 0.1 Mtpa of material will take place in the TSF area whilst an expected 2.5 Mtpa will be excavated from the area of evaporation ponds. This material will partly be used in the construction itself and partly be hauled to either the western or the eastern emplacement as estimated in Table A.4.2. The activity in the evaporation ponds area was estimated to result in an annualised emission of 882.5 tonnes.

The total annual estimated emission of 2186.5 tonnes also includes wind erosion of the exposed pit area, western and eastern emplacements, the TSF area and evaporation ponds.

Emissions in Year 5

The mining activity in Year 5 would take place in several small pits. The most active pits are expected to be pit 5-7 in the eastern section and pits 5-9 and 5-11 in the western section of the mine. A total of 2.0 Mtpa of high grade ore will be extracted and hauled to the stockpile area and ROM pad at the processing plant. Previously extracted low grade ore will remain stockpiled between the two sections of the mine. Two waste emplacement areas (western and eastern) will be active and will receive an estimated 7.035 Mtpa of waste rock.

The total annual emission of particulate matter (atmospheric dust expressed as total suspended particulates - TSP) was estimated at 2268.9 tonnes (Attachment A.4, Table A.4.3). Extraction and in-pit haulage of raw material was estimated to contribute 436.0 tonnes to the total. It may be noted that all dust particles were assumed to reach the orifice of the open pit irrespective of the depth below the surface at which they were emitted. The fact that no retention of particles in the pit was modelled renders the emission estimates conservative, i.e. the estimates are likely to be higher than the actual amount of particles escaping from the pit area.

Out-of-pit haulage of ore for stockpiling and processing will generate 193.6 tonnes. Passive stockpile of low grade ore will add 131.4 tonnes and the operations at the processing plant including the handling of high grade ore a further 623.4 tonnes. Operations in the waste emplacement areas would add 569.1 tonnes, wind erosion of the exposed areas a further 315.4 tonnes.

Emplacement areas and the ore stockpiling and handling areas were estimated to be the strongest sources of dust emissions contributing 39 per cent and 33.3 per cent of the total emission respectively.

Emissions in Year 10

Most of the mining in Year 10 will be in the eastern section of the mine in pit 10-2. The size of the pit will increase and the depth will reach 52 metres. The ore extraction rate will increase to 2.17 Mtpa consisting of 1.31 Mtpa of high grade and 0.86 Mtpa of low grade ore. High grade ore will be delivered to the ROM pad whilst low grade ore will be stockpiled and reclaimed as required.

The amount of waste rock will be lower than in Year 5. A total of 4.68 Mtpa will be hauled to the eastern emplacement which will reach a height of approximately 30 metres. The western emplacement is expected to be largely inactive in Year 10 with only wind erosion of its surface area contributing to the emission.

The total annual emission of particulate matter was estimated at 2565.3 tonnes. Details of the emission inventory and the amounts likely to be contributed by the individual groups of mining activities are given in Table A.4.4 in Attachment A.4.

Waste emplacement with a total of 1033.3 tonnes (40.3 per cent) and the ore storage and handling areas with 696.1 tonnes (27.1 per cent) would again be the strongest sources of dust emissions.

Emissions in Year 20

The amount of waste rock to be removed will increase after Year 13 of the operation. In Year 20, 8.48 Mtpa of waste rock will be mined together with 2.0 Mtpa of ore. About 80 per cent of the ore (1.60 Mtpa) will be low grade. Mining will be in 2 large pits, one in the east and one in the west. The depth of the pits will reach 64 metres.

Both waste emplacement areas will be used and will have sections of the emplacements at various stages of rehabilitation and revegetation. The expected heights are about 30 metres for the emplacements.

Details of the dust emission inventory are given in Attachment A.4, Table A.4.5. The annual emission was estimated to be 3748.7 tonnes. Almost 45 per cent of the total emission will be from the emplacement areas.

Operations in the ore handling area were estimated to contribute about 31.3 per cent (1172.5 tonnes).

Summary of dust emissions

The results of dust emission estimates for Years 5, 10 and 20 of the operation, and for the construction (Year-1) are summarised in Table 6.2. The table also shows the quantities of ore and waste to be mined during the respective years, and the estimated amounts of atmospheric dust generated in the process of mining and handling of one tonne of ore (dust to ore ratios) in each of the modelled years of operation.

Table 6.2
Summary of dust emission estimates for the proposed construction and operation of the mine

Year	Annual emission of dust	Mined quantities		Dust:ore ratio
	(tonnes/yr)	(Mtpa) Ore	Waste	(kg/tonne)
Construction				
Year-1	2186.5	-	3.78	-
Operation				
Year 5	2268.9	2.0	7.035	1.13
Year 10	2565.3	2.17	4.68	1.18
Year 20	3748.7	2.0	8.48	1.87

The calculated dust to ore ratios ranged from 1.13 kg/tonne in Year 5 to 1.87 kg/tonne in Year 20. No dust to ore ratio was calculated for the construction period as construction activity is not normally characterised by a reference to dust to ore ratios. The calculated ratios for the operation are comparable to ratios which were determined for most open cut coal mine developments in New South Wales and confirm the conservative nature of the dust emission estimates in this assessment. It can be expected that the generally higher moisture content of both the ore and the waste rock at Syerston than the typical moisture contents of coal and overburden in the Hunter Valley will result in actual lower dust emissions than those given in Table 6.2 during most times of the operation.

6.1.2 Modelling methodology and meteorological data

The estimated rates of dust emissions were applied together with the on-site meteorological data in a computer model of dust dispersion. The long-term version of the ISC3 model (ISC3LT 96113) was selected following a test run of both the short-term and long-term versions of the model as described further in Section 7.1.2. Most of the dust dispersion modelling in the last two decades has been based on the ISC code. ISC3 is the most recent stage in the development of the model and contains the use of Sehmel and Hodgson algorithms to simulate dry deposition of dust particles to the surface. The ISC3 model is finding increasing application in Australian conditions as the widely used AUSPLUME model in its present form cannot handle particle deposition with an acceptable degree of accuracy.

The meteorological data file (Section 5.2.2) was processed into the STAR format (frequency distribution of wind speed, wind direction and atmospheric stability) using the records which were collected over a full year for 24 hours a day.

The emission rate was varied with wind speed (6 classes) and atmospheric stability (6 classes) to incorporate a directional and intensity variation of the wind erosion term in the model. The grid of receptor points for postprocessing and contour plotting covered an area of 11 km by 9 km with a step size of 250 m. Discrete receptors corresponding to surrounding residences were also included in the model. The running time for one modelling case was about an hour. Samples of the input data are shown in Attachment A.3.

6.2 Modelling Results

6.2.1 Dust deposition

Year-1 (construction)

The meteorological data file was reprocessed to reflect the fact that most of the construction will be during the daytime. Predicted increases in the mean annual dust deposition rate are shown in Figure 6.1.

Mean annual increments of 4 g/m^2/month will be confined to the MLA area. Increments of 2 g/m^2/month were also predicted to be restricted to the MLA with the exception of a narrow strip of land to the east of MLA139. The mean annual increment corresponds to the construction of the evaporation ponds and the short-term (monthly) rates of dust deposition may be higher than the mean annual value during the most intense period.

The rate of dust deposition will decrease rapidly with the increasing distance from the MLA boundary. All non-Company owned residences located to the east of the MLA as well as the township of Fifield were predicted to experience mean annual increments of less than 0.2 g/m^2/month. There are two non-Company owned residences which will receive a mean rate of more than 0.2 g/m^2/month located to the south of MLA139. The predicted value of about 0.3 g/m^2/month however remains safely within the EPA amenity criterion of 2 g/m^2/month.

Year 5

Predicted increases in the mean annual rate of dust deposition from the extraction and handling of ore in Year 5 are presented in Figure 6.2 in a set of isopleths. The shape of the dust deposition contours reflected the direction of the main winds along the NE-SW axis and the position of the main dust generating sources.

The predicted increments in the annual dust deposition rate of 2 g/m^2/month and above will be confined to the MLA area.

All non-Company owned residences which are located in the vicinity of the proposed development were predicted to receive increases in the mean annual dust deposition rate of less than 0.4 g/m^2/month and in most cases less than 0.2 g/m^2/month.

The predicted increases remained well within the NSW EPA criterion for protection of amenity which requires the mean dust deposition rate not to increase by more than 2.0 g/m^2/ month.

Year 10

The concentration of mining activity in the northeastern section of the mine in Year 10 will result in a general displacement of the dust contours in that direction. The predicted increments in the mean annual dust deposition rate in Figure 6.3 however indicated that an increase of 2 g/m^2/month will remain confined almost entirely to the MLA area itself. A small section of the land immediately north of MLA 140 was predicted to experience a rate of between 2 and 3 g/m^2/month.

The predicted increase at the residence which is located further north was approximately 0.5 g/m^2/month. The increments at all other non-Company owned residences will be restricted to 0.2 g/m^2/month or less.

Year 20

Figure 6.4 contains a map of isopleths which indicate the predicted increases in the mean annual dust deposition in Year 20 of the proposed extraction. The position of the contour line which corresponds to an increase of 2.0 g/m^2/month was predicted to be again fully confined to the MLA area following a shift in the locations of the main dust generating sources.

An increase of about 0.4 g/m^2/month was predicted for the residence to the north of MLA 140. The nearest residences in the southwestern direction from the MLA were predicted to receive an average increase of about 0.3 g/m^2/month. The predicted increments in the mean annual dust deposition rates remained safely within the EPA amenity criterion.

6.2.2 Concentrations of total suspended particulates

Year-1 (Construction)

The predicted increases in the mean annual concentration of TSP during the most intensive 12 months of construction activities are shown in Figure 6.5.

The increase in the mean concentration levels will be less than 5 micrograms/m^3 at all non-Company owned residences. Increments of 60 micrograms/m^3 and higher will be contained within the MLA area.

Year 5

Figure 6.6 shows the predicted increases in the mean annual concentration of TSP in the ambient air in Year 5. The main trends in the predicted dust levels which were displayed in Figure 6.2 are also evident in the contours of TSP concentrations. The shape of the concentration isopleths was again determined by the location of the main dust sources and the prevailing wind directions.

The NHMRC guideline of 90 micrograms/m^3 refers to a total concentration of TSP in residential environments. The existing mean concentrations in the area were estimated to be about 20 to 30 micrograms/m^3 or less. An increase of at least 60 micrograms/m^3 would thus be needed to reach the limit value of 90 micrograms/m^3.

Mean annual concentrations of TSP were predicted to increase by about 60 micrograms/m^3 or more in the vicinity of the main dust generating sources and be fully contained within the MLA. Increments of 40 micrograms/m^3 will also be largely confined to the MLA area as well.

Increases of between 40 and 60 micrograms/m^3 in the mean annual concentration of TSP were predicted for small sections of land located outside the northern boundary of the MLA.

The nearest residence was predicted to receive an increase in the mean annual concentration of TSP of less than 15 micrograms/m^3. PM_{10} particles typically form about 40 to 50 per cent of the TSP particles and will therefore be limited to less than 7.5 micrograms/m^3.

All other non-Company owned residences were predicted to receive mean increments of less than 10 micrograms/m^3 of TSP.

Year 10

Emissions from mining and waste emplacement in the northeastern section of the mine in Year 10 are likely to displace the 60 micrograms/m^3 contour temporarily just outside the northern boundary of MLA 140 (see Figure 6.7). In all remaining directions, the increases in the mean annual TSP concentrations of 60 micrograms/m^3 will remain confined to the MLA area.

The mean annual concentration at the nearest residence to the north was predicted to increase by about 20 micrograms/m^3 for TSP and so less than 10 micrograms/m^3 for PM_{10}. The increases in TSP concentrations at all other non-Company owned residences will be less than 10 micrograms/m^3.

Year 20

The predicted distribution of mean annual concentrations of TSP in Year 20 will be similar to Year 10. Increments of 60 micrograms/m^3 will be restricted to within the MLA boundaries except for a small portion of the north to the north of the MLA (see Figure 6.8).

The nearest residence to the north will receive approximately 20 micrograms/m^3, residences to the southwest about 15 micrograms/m^3. The predicted increments at all non-Company owned residences thus remained within the guideline limits.

6.3 Impact Assessment

The modelling predictions confirmed that the levels of particulate matter at all non-Company owned residences, in terms of both dust deposition and concentration of suspended particulates, will remain safely within the applicable goals.

The levels of particulate matter in the air outside the MLA and on land which is not used for residential purposes will also remain within the guideline limits at all times in the western, southern and eastern directions.

The modelling identified a narrow portion of non-residential land immediately to the north of the MLA and to the proposed locations of waste emplacement areas at the mine site which is likely to experience increases in the mean annual levels of dust deposition and TSP concentration in excess of the amenity criteria at some stage in the Project development. The timing of those increments was predicted to coincide with times of maximum activity in the emplacement areas.

Prior to the operation of the mine and the processing plant, construction activity in the southeastern section of the MLA corresponding to the areas of evaporation ponds and TSF was predicted to increase dust deposition in a narrow strip of land located immediately to the east of MLA 139 to above 2 g/m^2/month. Residences which are located to the east and south of MLA139 will not be affected.

7 MODELLING AND ASSESSMENT OF FUGITIVE DUST EMISSIONS - LIMESTONE QUARRY

An outline of the proposed operations at the limestone quarry was presented in Section 3.1.4. Further details are contained in the main volume of the EIS.

7.1 Methodology and Input Data

7.1.1 Dust emissions

Years 5 and 21 of the operation were selected for compilation of detailed dust emission inventories and subsequent modelling of dust dispersion. The production rates in Years 5 and 21 would reach 560 000 tpa of high grade ore. An additional 136 838 tpa of low grade ore and waste would also be extracted and taken to waste emplacement.

The rates of dust emissions were determined for individual extraction activities including drilling and blasting, loading and haulage of both the ore and the waste rock, and handling and processing at the processing plant. The dust emission factors which were used in the estimates are listed in Table A.5.1 in Attachment A.5. Details of the dust emission inventories are also given in Attachment A.5 (Tables A.5.2 and A.5.3). Particle size distributions from Table 6.1 were again applied.

Emissions in Year 5

The extraction activity in Year 5 would take place in the south-eastern half of the extraction area. The expected tonnage of raw feed for processing is 560 000 tpa. An estimated 136 838 tpa of waste would also be removed and emplaced in the southern section of the emplacement area.

The total annual emission of particulate matter (atmospheric dust expressed as total suspended particulates - TSP) was estimated at 431.7 tonnes (Attachment A.5, Table A.5.2). Extraction and haulage of raw material was estimated to contribute 105.5 tonnes to the total. The estimated emission from the processing plant was 125.0 tonnes. Operations in the emplacement area would add 31.2 tonnes, wind erosion of the exposed areas a further 170.0 tonnes. It may be noted that all dust particles were assumed to reach the orifice of the open pit irrespective of the depth below the surface at which they were emitted. The fact that no retention of particles in the pit was modelled renders the emission estimates conservative, i.e. the estimates are likely to be higher than the actual amount of particles escaping from the pit area.

Emissions in Year 21

Extraction in Year 21 would progress further to the northwest and the emplacement area would extend to the northern half as well.

The estimated annual emission of TSP would rise to 572.2 tonnes in Year 21 (Attachment A.5, Table A.5.3).

7.1.2 Modelling methodology and meteorological data

The estimated rates of dust emissions were applied together with the on-site meteorological data in a computer model of dust dispersion. The ISC3ST model (Version 97363) was used first to include hourly variations in the emission rate due to daytime working hours only for most parts of the operation. The emissions outside the working hours then consisted of passive wind erosion of exposed areas and the movement of trucks transporting the product from the stockpile area via the access road. Wind erosion was only able to be modelled as a constant term with no dependence on wind speed and wind direction.

The meteorological data file as described in Section 5.2.2 was reprocessed into ISC format and contained a full year of hourly data.

The running time for one modelled year of emissions and a grid of receptor points covering an area of 9 km by 7 km with a step size of 250 m was approximately 67 hours using a Pentium 333 MHz processor. Because of the considerable running times and the fact that the ISC3ST model could not be applied to vary the wind erosion term with wind speed and direction in addition to hourly variations in the emission rate, the long-term version of the ISC3 model (ISC3LT 96113) was then deployed. The meteorological data was reprocessed into the STAR format (frequency distribution of wind speed, wind direction and atmospheric stability) using the records which were collected over a full year during the times between 07h00 and 18h00.

The emission rate was then varied with wind speed (6 classes) and atmospheric stability (6 classes) to incorporate a directional and intensity variation of the wind erosion term in the model. The running time for the ISC3LT model was about an hour. Samples of the input data are shown in Attachment A.6.

The output files from both models including contour plots for Year 5 data were examined and the result compared. As no major differences between the results from the two model versions were found, the ISC3LT model was used in all subsequent estimates including the modelling of fugitive dust from the Syerston mine which was presented in the previous section.

7.2 Modelling Results

7.2.1 Dust deposition

Year 5

Predicted increases in the mean annual rate of dust deposition from the extraction and processing of limestone in Year 5 are presented in Figure 7.1 in a set of isopleths. The shape of the dust deposition contours reflected the direction of the main winds and the position of the main dust generating sources.

Figure 7.1 indicates that increases in the annual dust deposition rate of 2 g/m^2/month and above will be restricted largely to the quarry MLA area. Increments of 2 g/m^2/month were also predicted for small portions of the land outside the MLA which are located immediately to the west of the processing plant, and to the south of the extraction area.

All non-Company owned residences which are located in the vicinity of the proposed development were predicted to receive increases in the mean annual dust deposition rate of 0.2 g/m^2/month or less.

The predicted increases remained well within the NSW EPA criterion for protection of amenity which requires the mean dust deposition rate not to increase by more than 2.0 g/m^2/month.

Year 21

Figure 7.2 contains a map of isopleths which indicate the predicted increases in the mean annual dust deposition in Year 21 of the proposed extraction. The position of the contour line which corresponds to an increase of 2.0 g/m^2/month extended a little further reflecting an increase in the area used for emplacement of low grade ore and waste.

The displacement of the contour lines was only minor and the predicted increments in the mean annual dust deposition rates remained safely within the EPA amenity criterion.

7.2.2 Concentrations of total suspended particulates

Year 5

Figure 7.3 shows the predicted increases in the mean annual concentration of TSP in the ambient air. The main trends in the predicted dust levels which were displayed in Figure 7.1 are also evident in the contours of TSP concentrations. The shape of the concentration isopleths was again determined by the location of the main dust sources and the prevailing wind directions.

The NHMRC guideline of 90 micrograms/m^3 refers to a total concentration of TSP in residential environments. The existing mean concentrations in the area were estimated to be about 20 to 30 micrograms/m^3 or less. An increase of at least 60 micrograms/m^3 would thus be needed to reach the limit value of 90 micrograms/m^3.

Mean annual concentrations of TSP at the Project site were predicted to increase by about 60 micrograms/m^3 or more in the vicinity of the main dust generating sources and contained within the MLA. Increments of 40 micrograms/m^3 will be almost entirely confined to the MLA area as well.

An increase of between 40 and 60 micrograms/m^3 in the mean annual concentration of TSP was predicted for a small area located just outside the western boundary of the MLA. This small portion of land is not used for residential purposes (Black Range have advised they hold an option to purchase this property).

The nearest residences were predicted to receive an increase in the mean annual concentration of TSP of less than 5 micrograms/m^3. PM$_{10}$ particles typically form about 40 to 50 per cent of the TSP particles and will therefore be limited to less than 2.5 micrograms/m^3.

Year 21

A slight displacement in the TSP concentration contours mainly towards the north was predicted in Figure 7.4 as a result of increased utilisation of the main emplacement area. Despite the displacement, however, the predicted increases in the mean annual concentrations of TSP in the ambient air of 40 micrograms/m^3 and higher remained confined to the MLA area with the exception of the small portion of land immediately to the west.

The predicted increments in the ambient air at all non-Company residences remained similarly below 5 micrograms/m^3.

7.3 Impact Assessment

The modelling predictions confirmed that the levels of particulate matter outside the MLA area, in terms of both dust deposition and concentration of suspended particulates, will remain safely within the applicable goals.

8 CONCLUSIONS

The impact assessment of the proposed construction and operation of the proposed development on air quality was carried out quantitatively using details of estimated emissions to air, on-site records of meteorological conditions and air quality goals and objectives which were specified by the NSW EPA.

The assessment followed closely the EPA and DUAP requirements and addressed emissions of atmospheric gases as well as particulate matter. The Project will be constructed and operated using standard air quality controls and safeguards including both emission and ambient air monitoring.

In relation to air emissions from the processing plant, the modelling predictions indicated that the plant will be capable of operating without breaching the NEPM goals for concentrations of SO_2 and NO_2 and the Victorian design concentration of H_2S in the ambient air at all locations outside the Project site boundaries.

The levels of particulate matter (atmospheric dust) in the ambient air at all non-Company owned residences in the vicinity of the Project site at Syerston will remain safely within the applicable guideline limits. Narrow portions of non-residential land were identified to the north and the east of the MLA area which are likely to receive dust levels in excess of the EPA amenity criteria at some stage of the mine construction or operation.

An air quality management plan will be designed to minimise the occurrence of possible exceedances. The plan will include a strategy for the control of short-term dust episodes during intervals of adverse weather conditions, and ambient air monitoring.

Given the conservative nature of the emission estimates, mostly as a result of the high moisture contents of Syerston ore and waste rock, it can be expected that actual dust emissions will be lower than predicted during most times of the operation.

Finally, the modelling predictions for the limestone quarry confirmed that the levels of particulate matter in the air outside the quarry MLA area, in terms of both dust deposition and concentration of suspended particulates, will remain safely within the regulatory limits.

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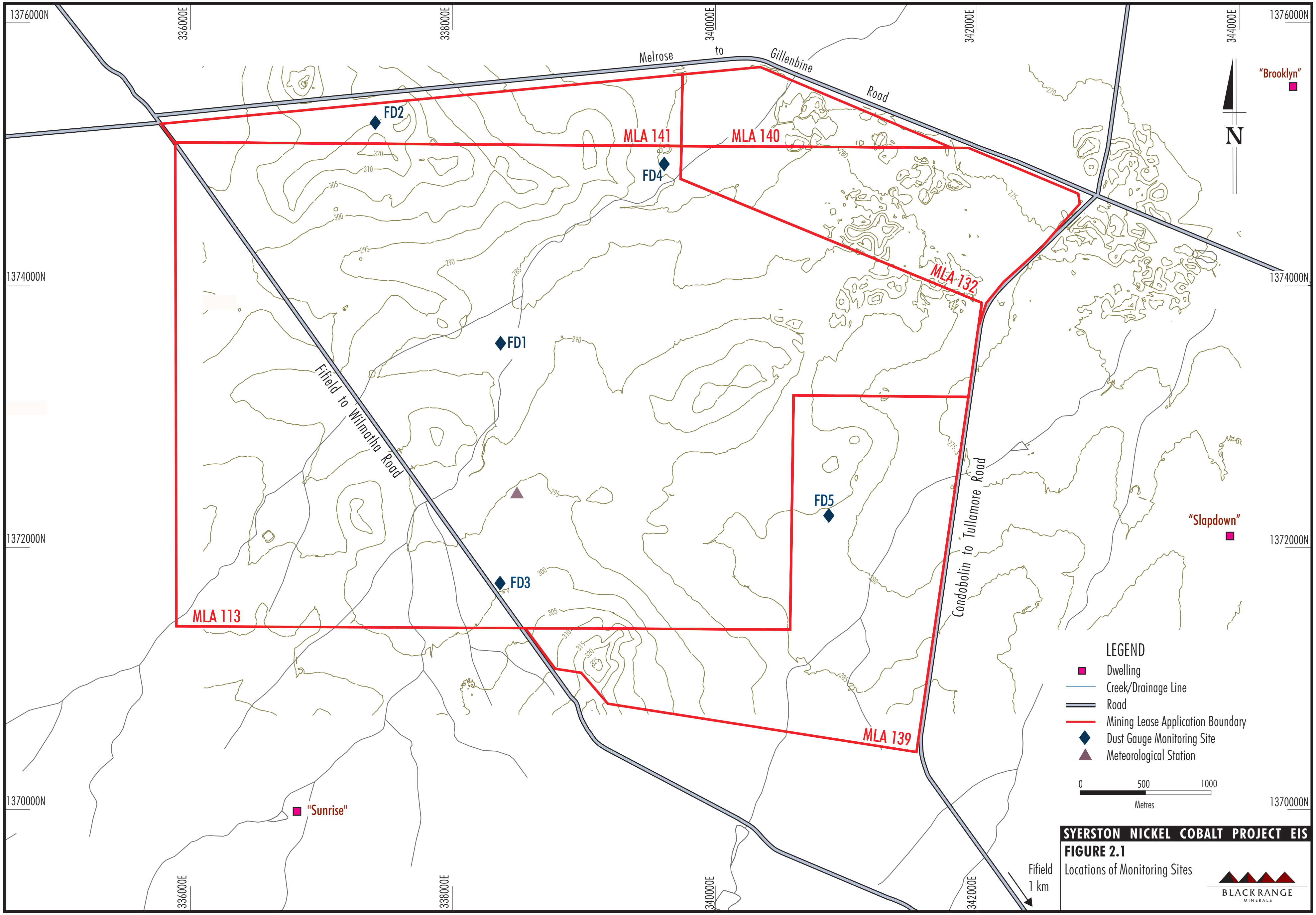
FIGURES

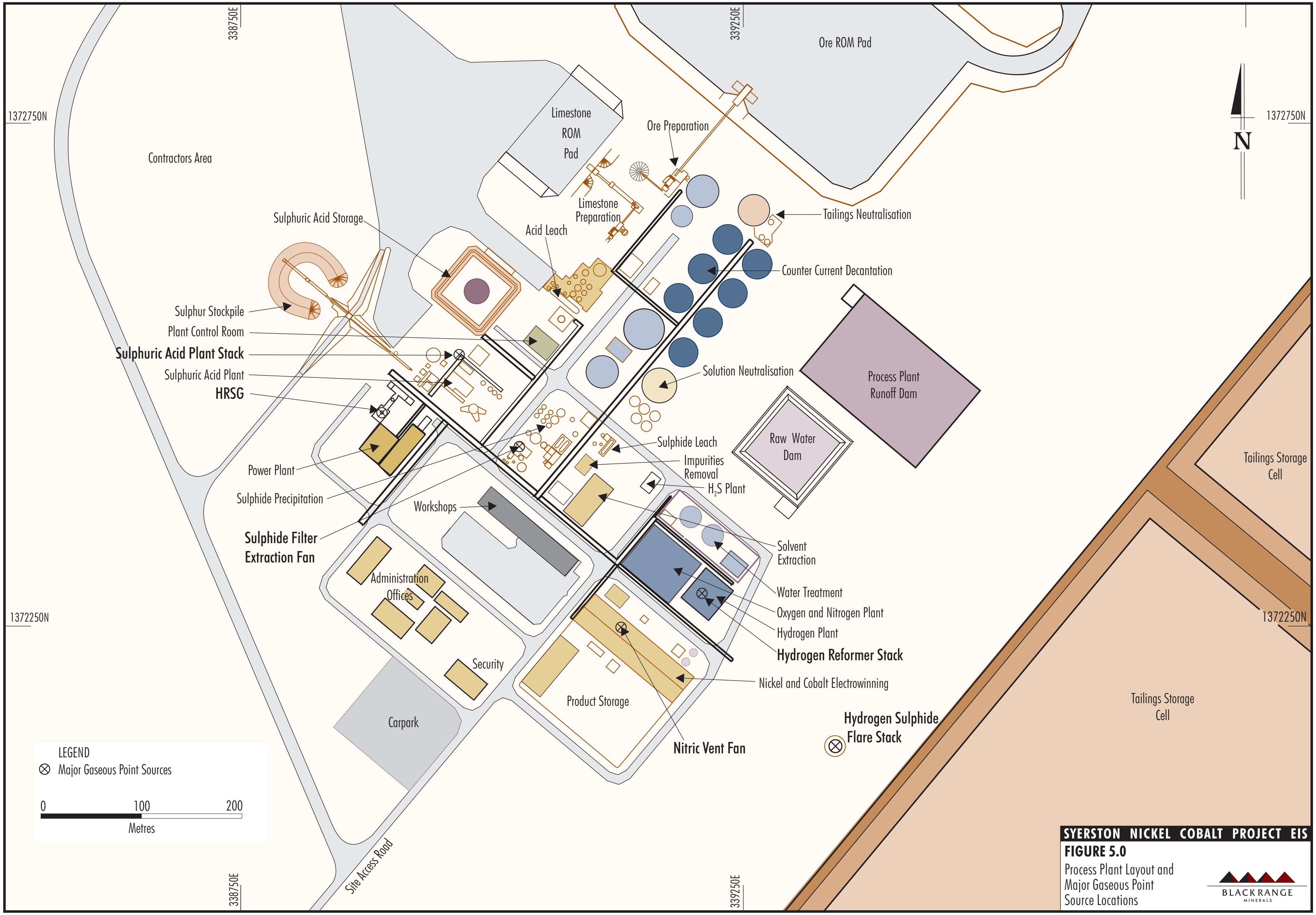


SYERSTON NICKEL COBALT PROJECT EIS

FIGURE 2.1

Locations of Monitoring Sites

BRM-98-01-AQ_002E

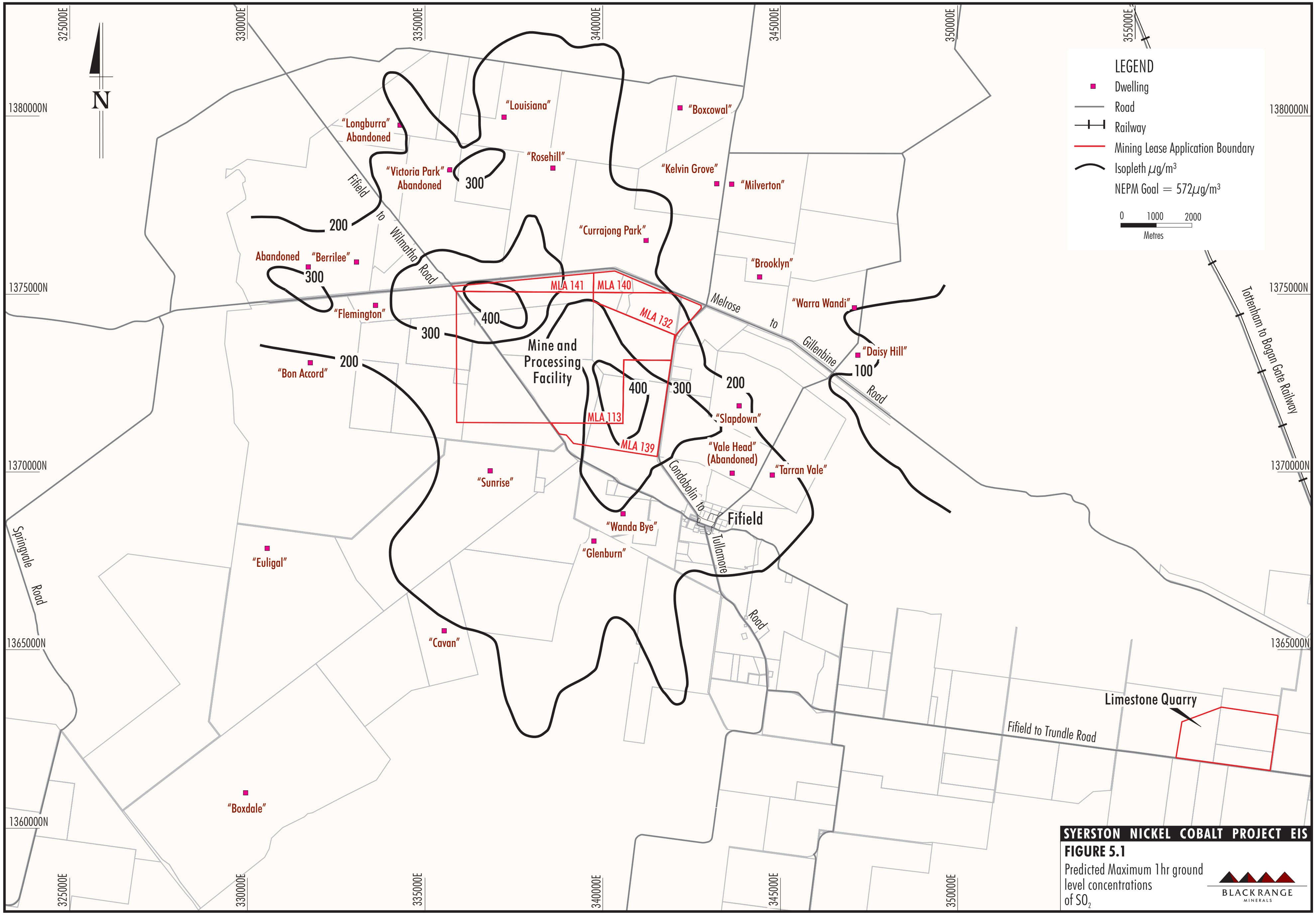


SYERSTON NICKEL COBALT PROJECT EIS

FIGURE 5.0

Process Plant Layout and Major Gaseous Point Source Locations

BRM-98-01-AQ_020C

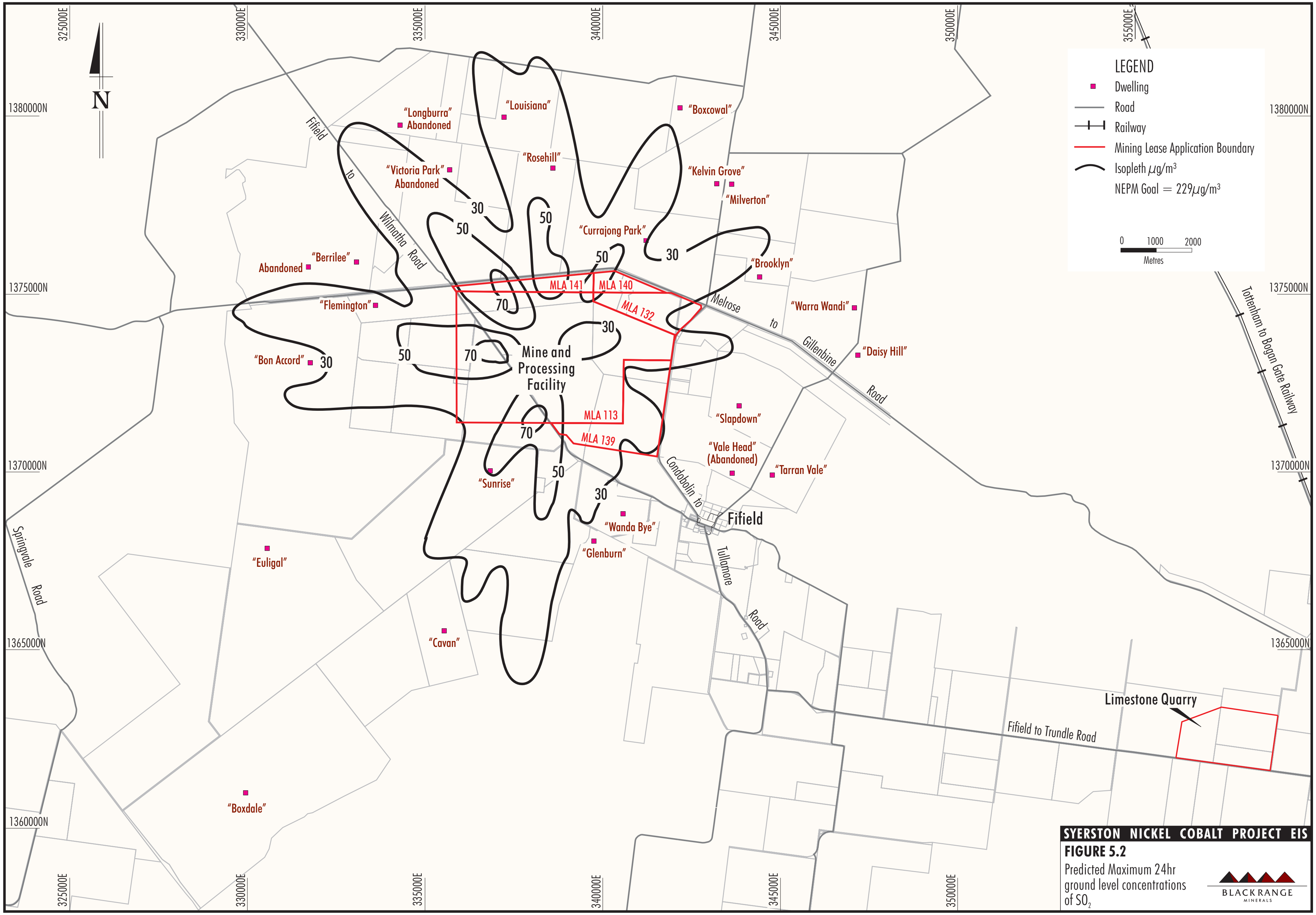


SYERSTON NICKEL COBALT PROJECT EIS

FIGURE 5.1

Predicted Maximum 1hr ground level concentrations of SO_2

BRM-98-01-AQ_001F

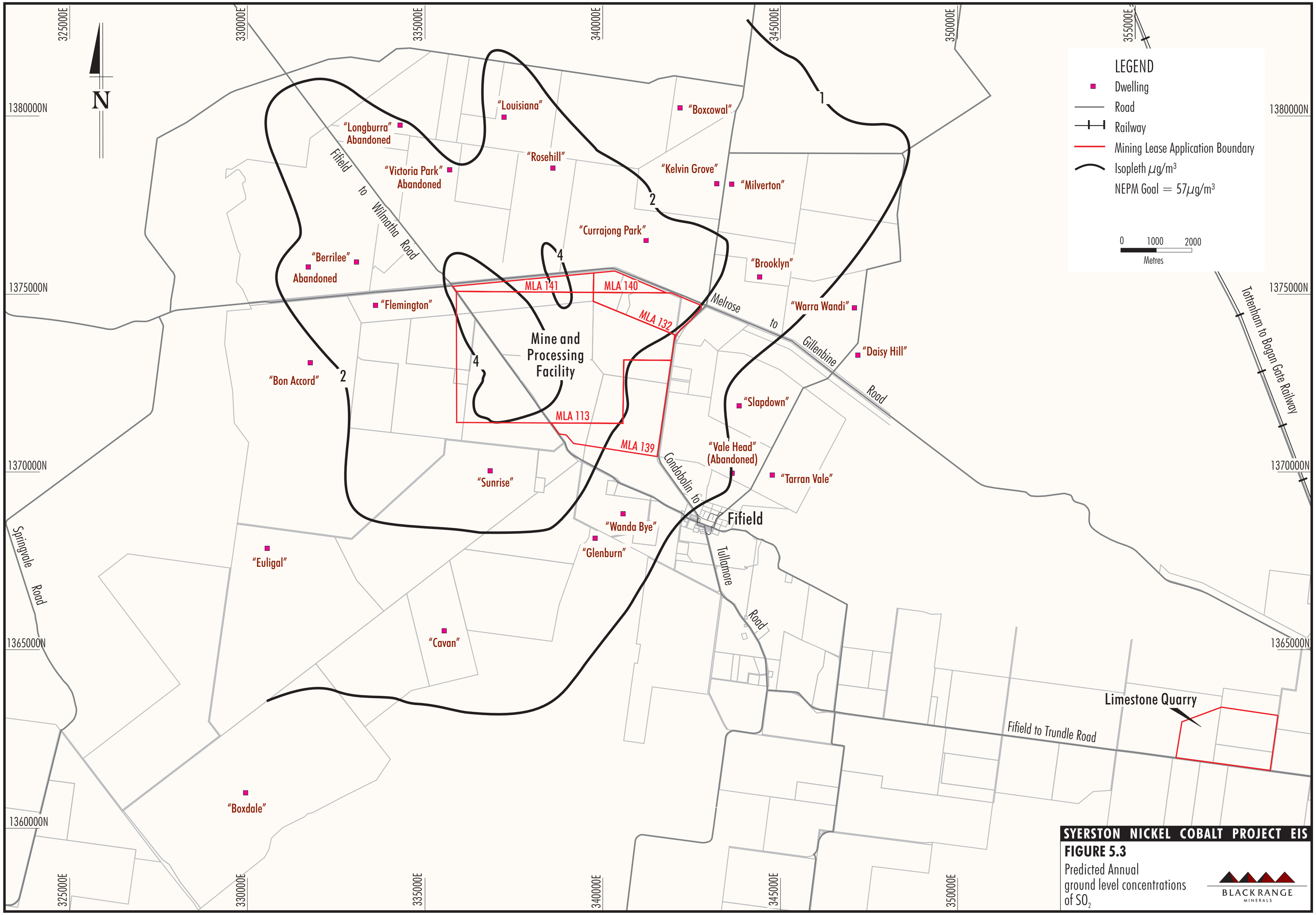


SYERSTON NICKEL COBALT PROJECT EIS

FIGURE 5.2

Predicted Maximum 24hr ground level concentrations of SO_2

BRM-98-01-AQ_004E

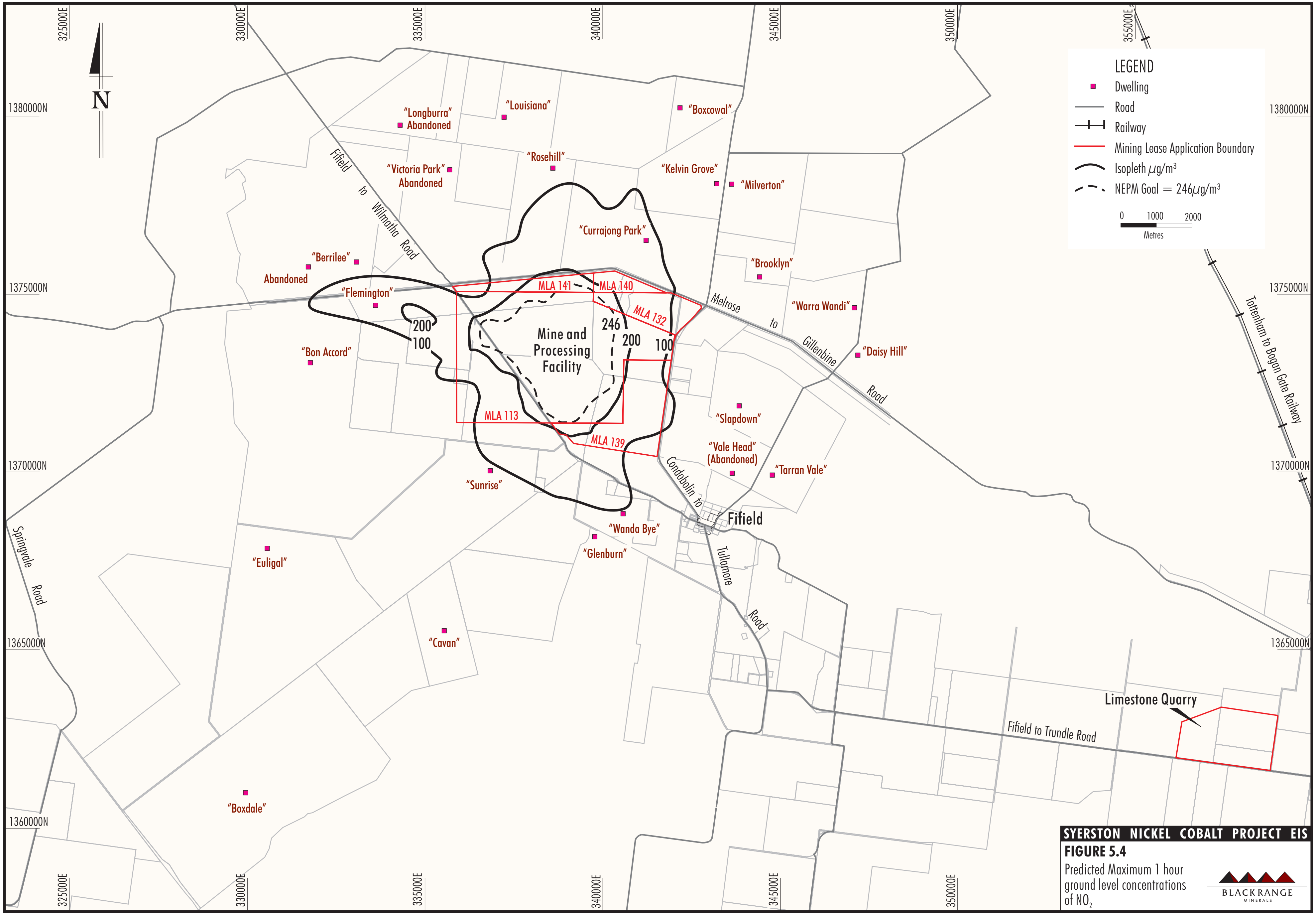


SYERSTON NICKEL COBALT PROJECT EIS

FIGURE 5.3

Predicted Annual ground level concentrations of SO_2

BRM-98-01-AQ_005E

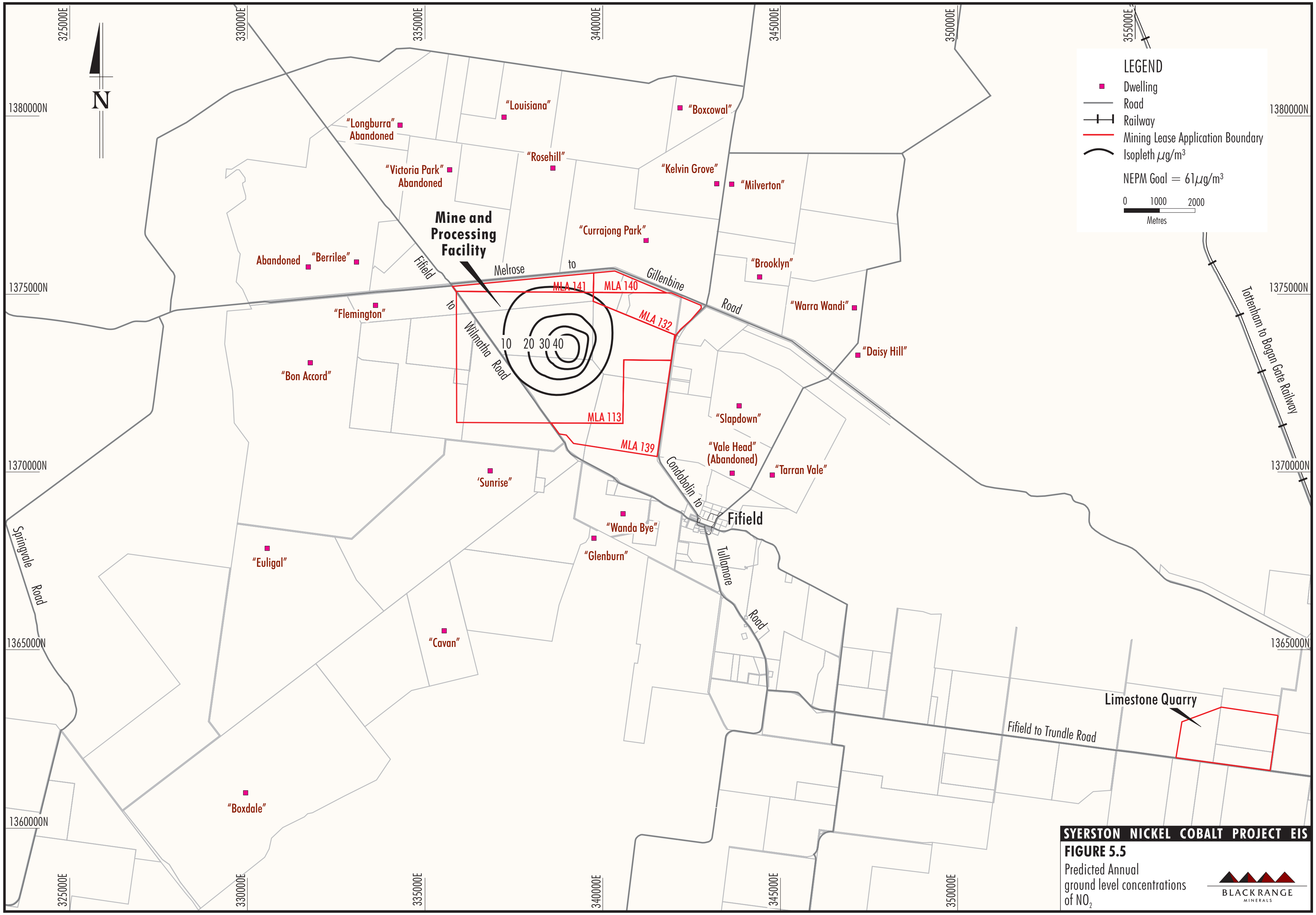


SYERSTON NICKEL COBALT PROJECT EIS

FIGURE 5.4

Predicted Maximum 1 hour ground level concentrations of NO_2

BRM-98-01-AQ_006F

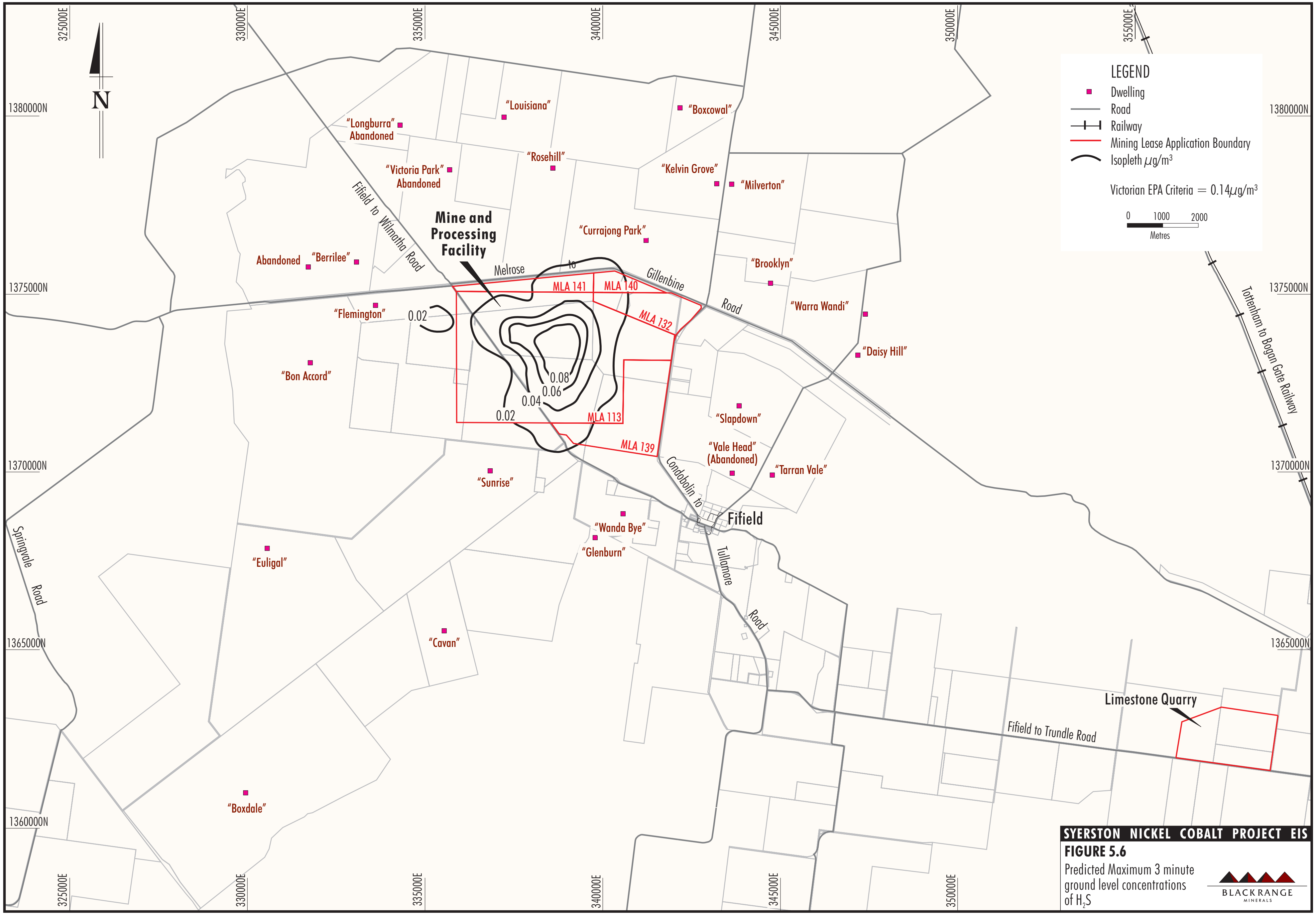


SYERSTON NICKEL COBALT PROJECT EIS

FIGURE 5.5

Predicted Annual ground level concentrations of NO_2

BRM-98-01-AQ_007E



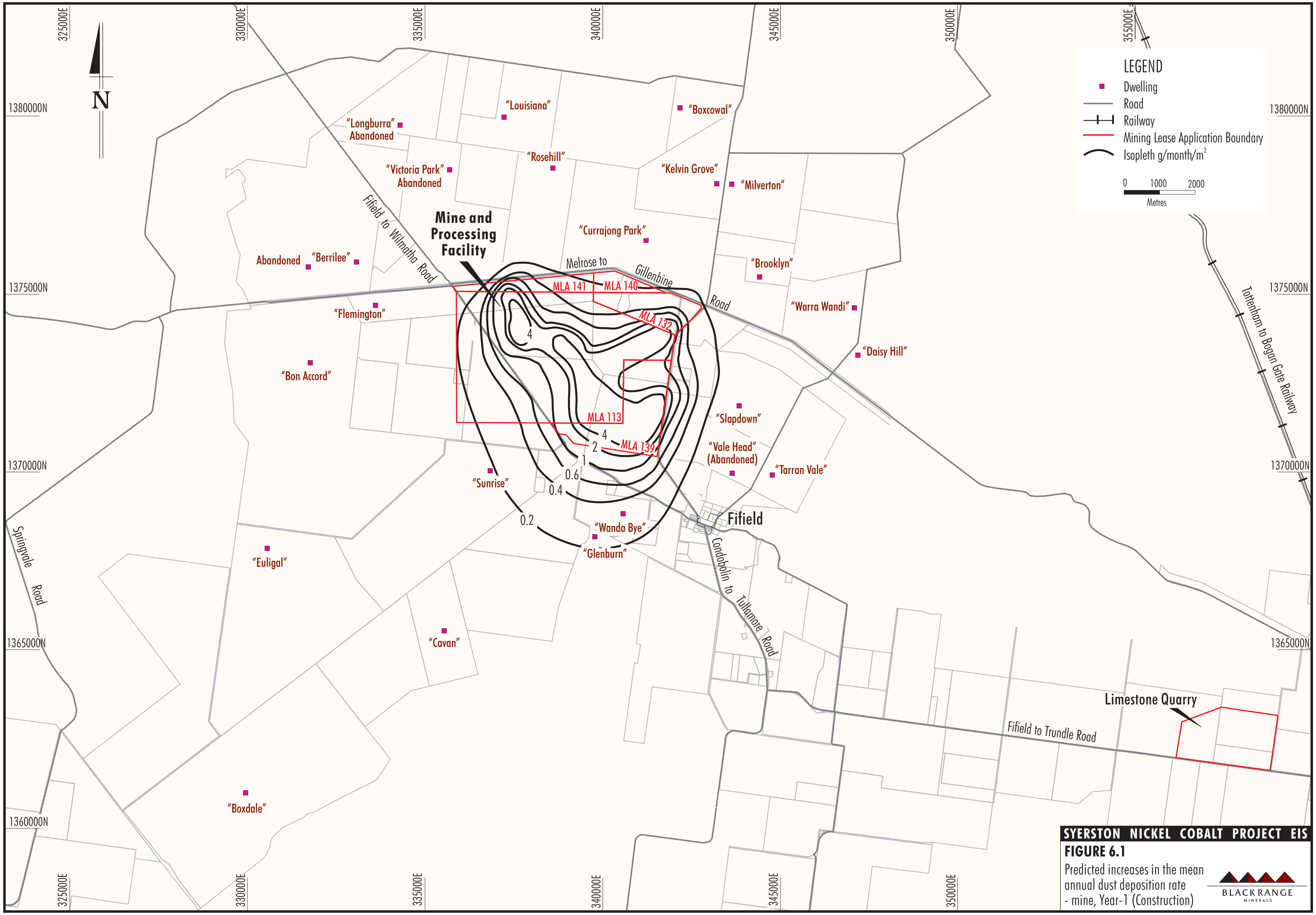
SYERSTON NICKEL COBALT PROJECT EIS

FIGURE 5.6

Predicted Maximum 3 minute ground level concentrations of H_2S

BLACKRANGE MINERALS

BRM-98-01-AQ_008D



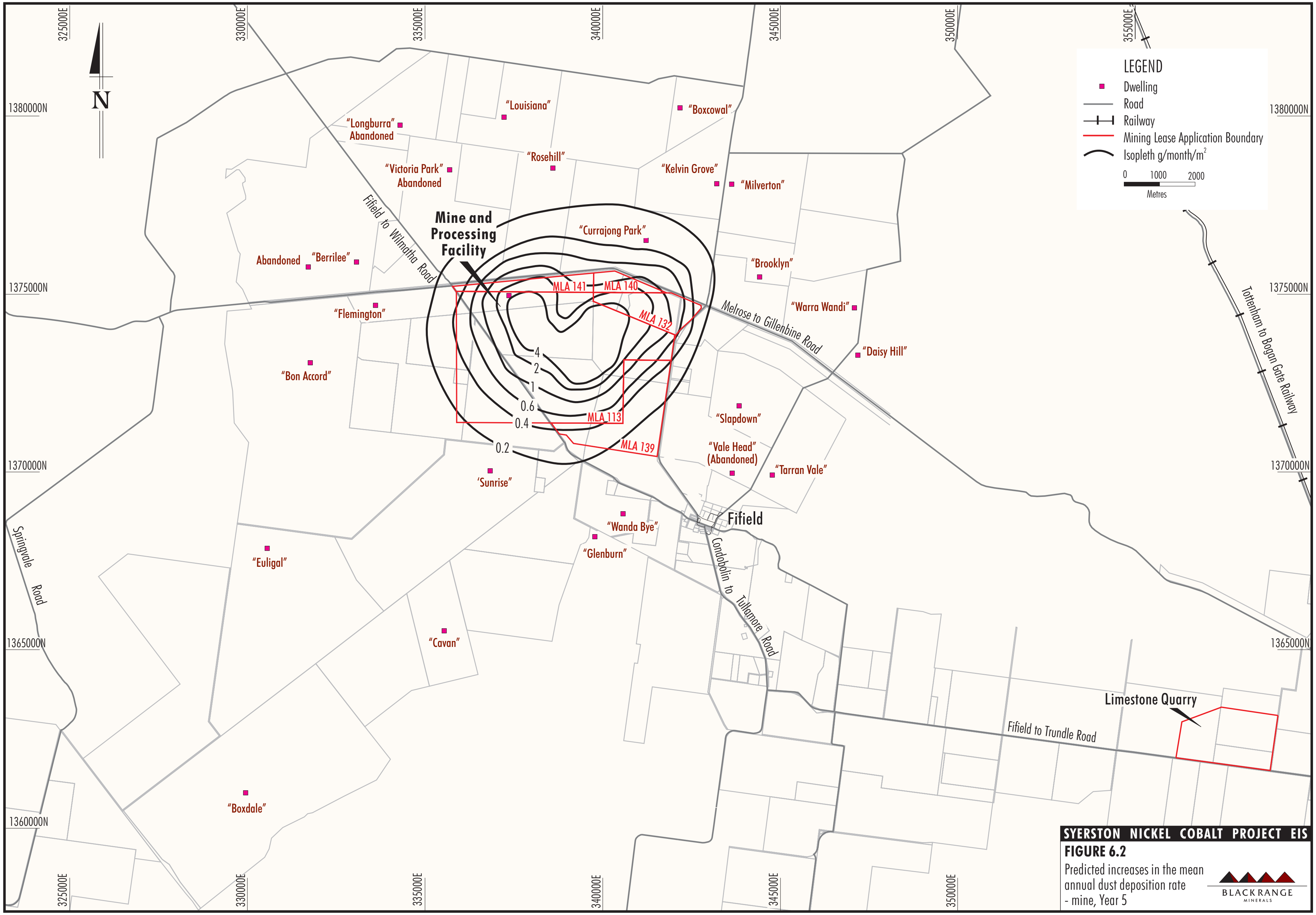
SYERSTON NICKEL COBALT PROJECT EIS

FIGURE 6.1

Predicted increases in the mean annual dust deposition rate - mine, Year-1 (Construction)

BLACKRANGE MINERALS

BRM-98-01-AQ_013E



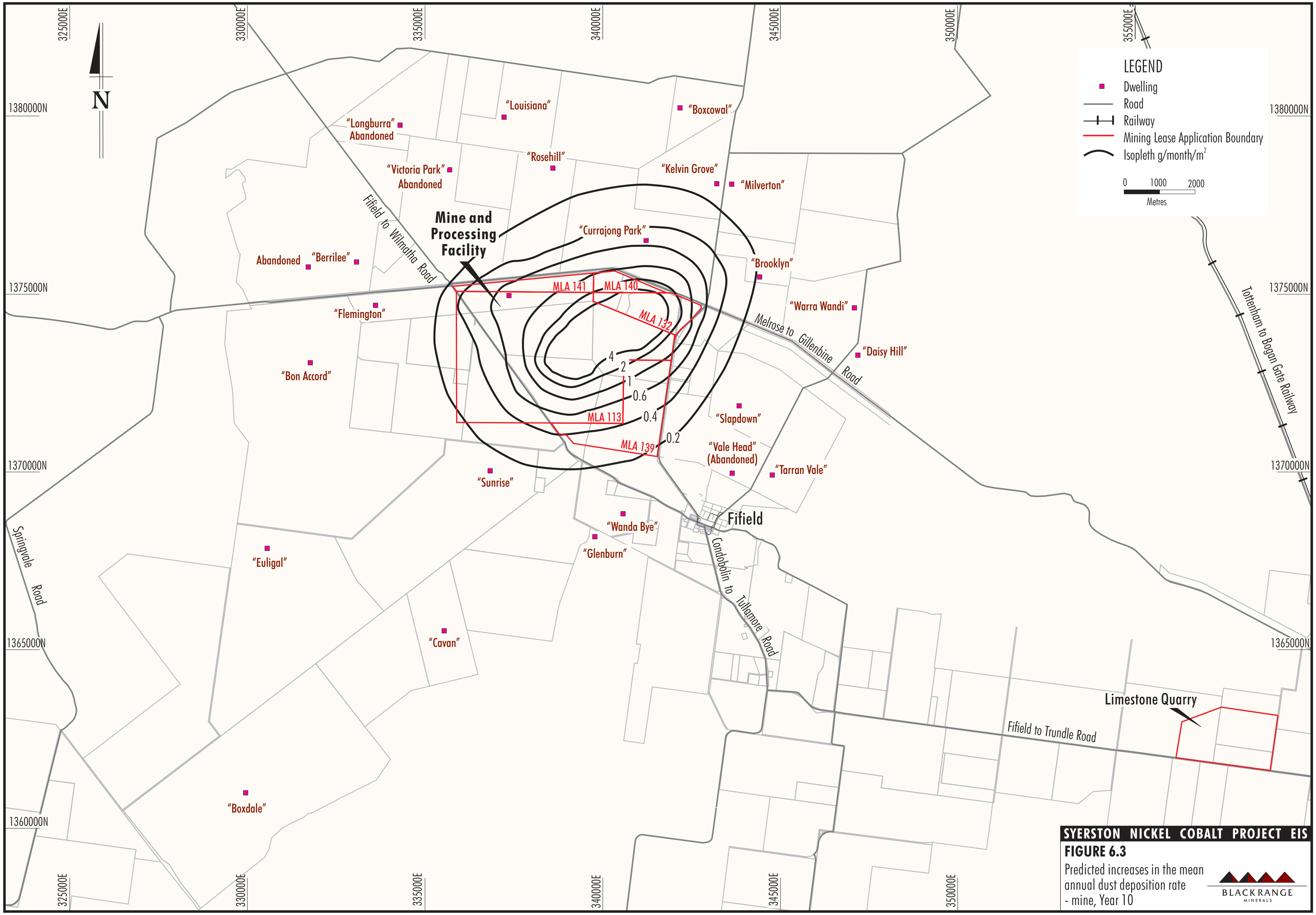
SYERSTON NICKEL COBALT PROJECT EIS

FIGURE 6.2

Predicted increases in the mean annual dust deposition rate - mine, Year 5

BLACKRANGE MINERALS

BRM-98-01-AQ_014E

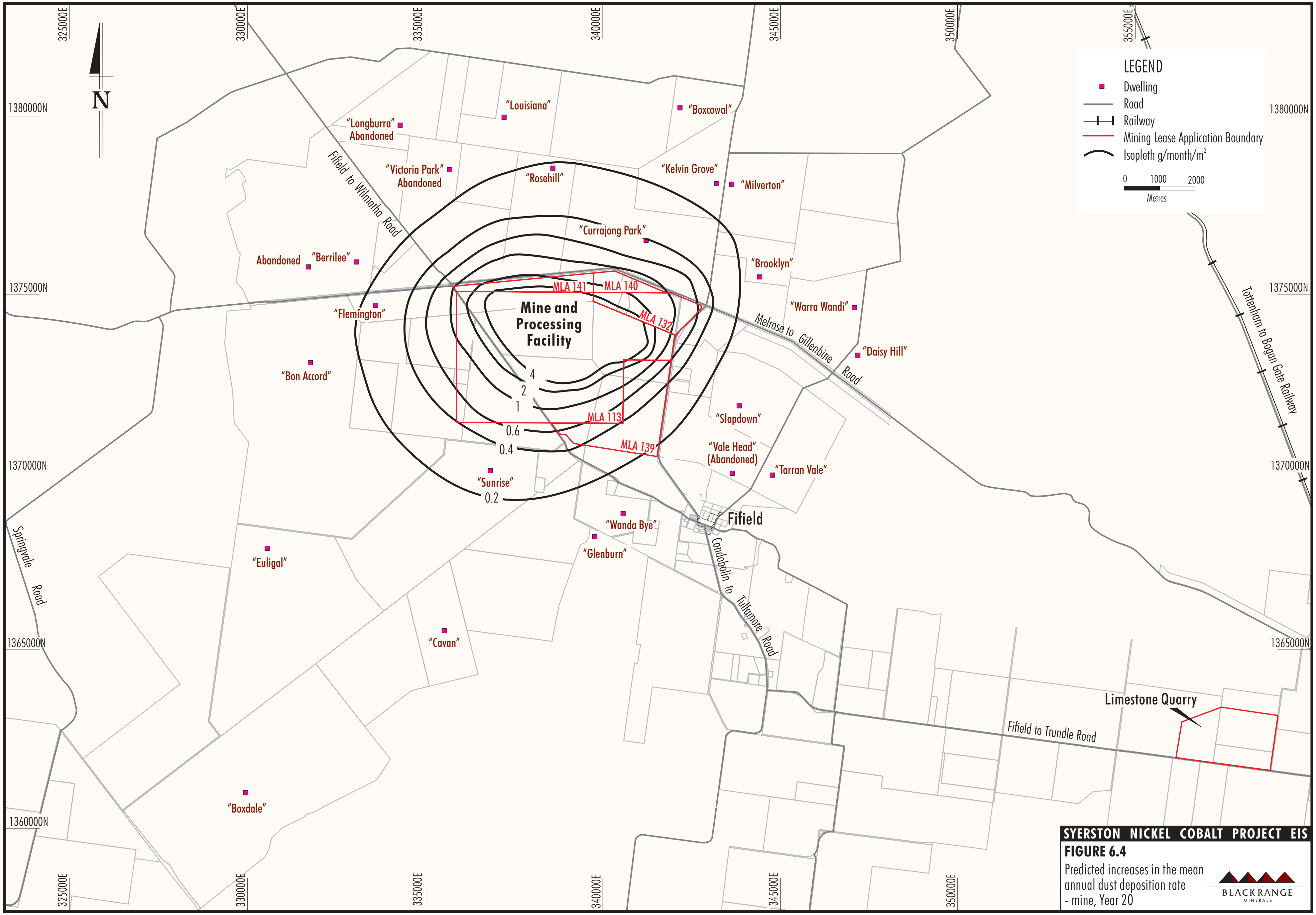


SYERSTON NICKEL COBALT PROJECT EIS

FIGURE 6.3

Predicted increases in the mean annual dust deposition rate - mine, Year 10

BRM-98-01-AQ_015E

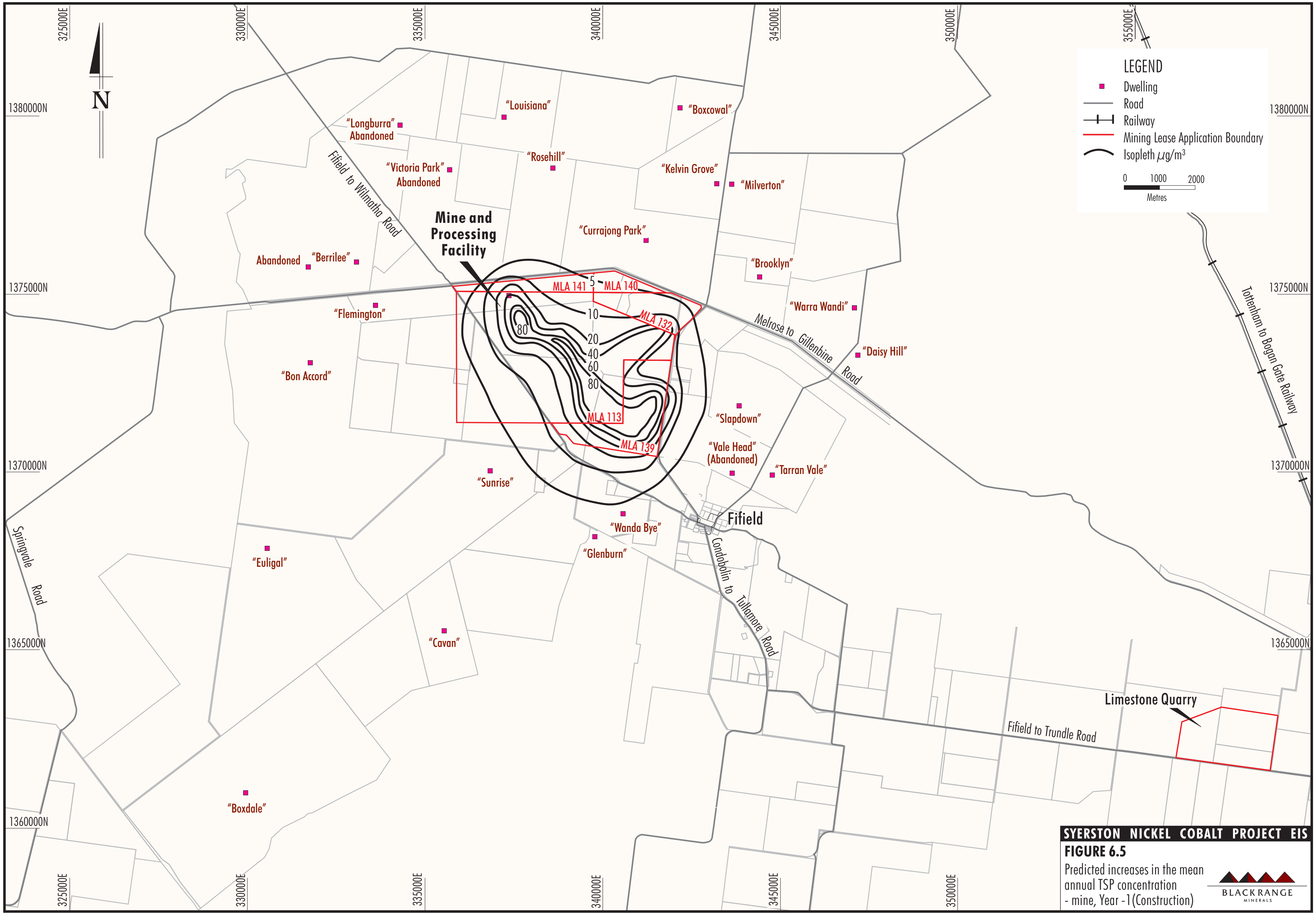


SYERSTON NICKEL COBALT PROJECT EIS

FIGURE 6.4

Predicted increases in the mean annual dust deposition rate - mine, Year 20

BRM-98-01-AQ_016E

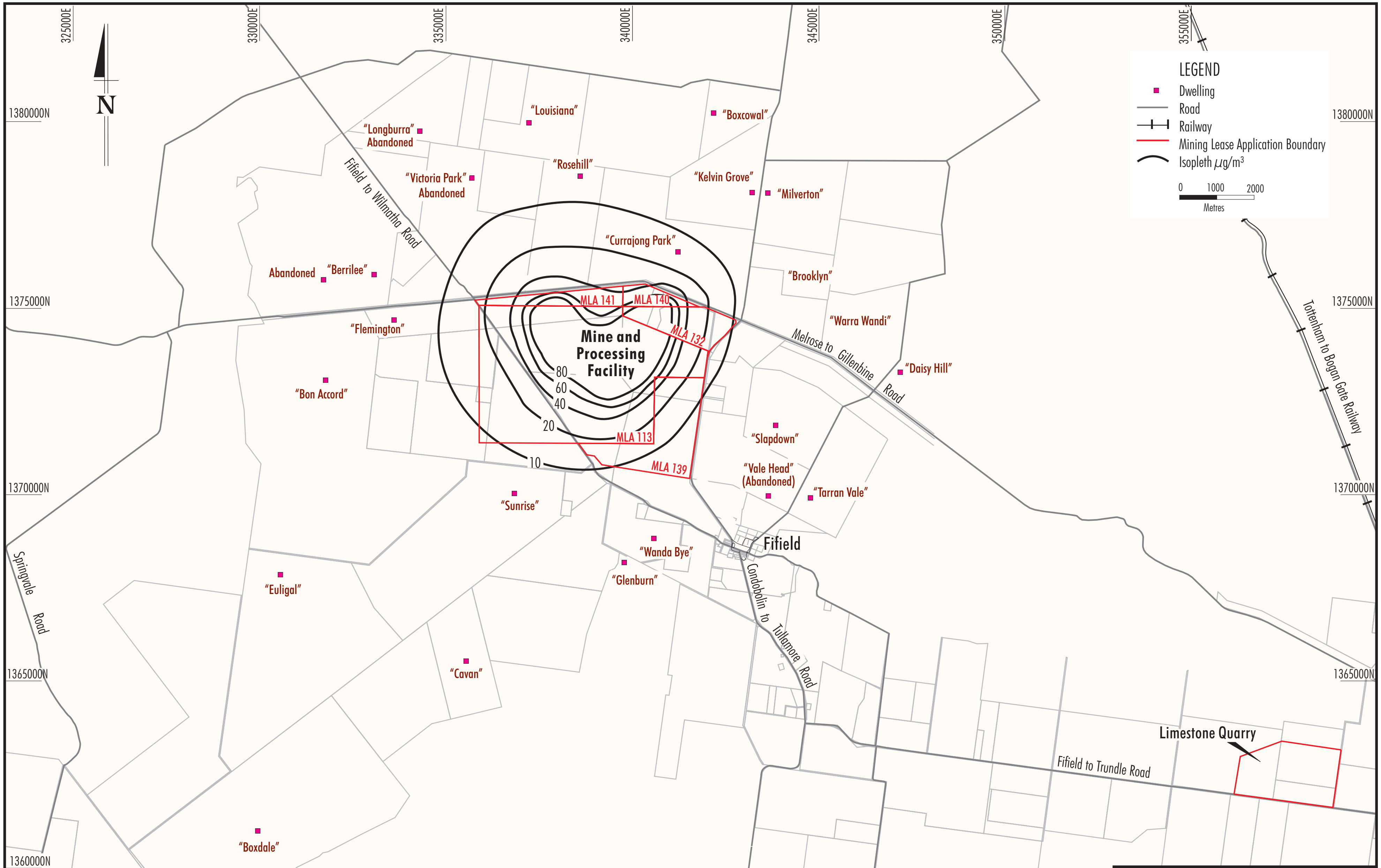


SYERSTON NICKEL COBALT PROJECT EIS

FIGURE 6.5

Predicted increases in the mean annual TSP concentration - mine, Year -1 (Construction)

BRM-98-01-AQ_017E

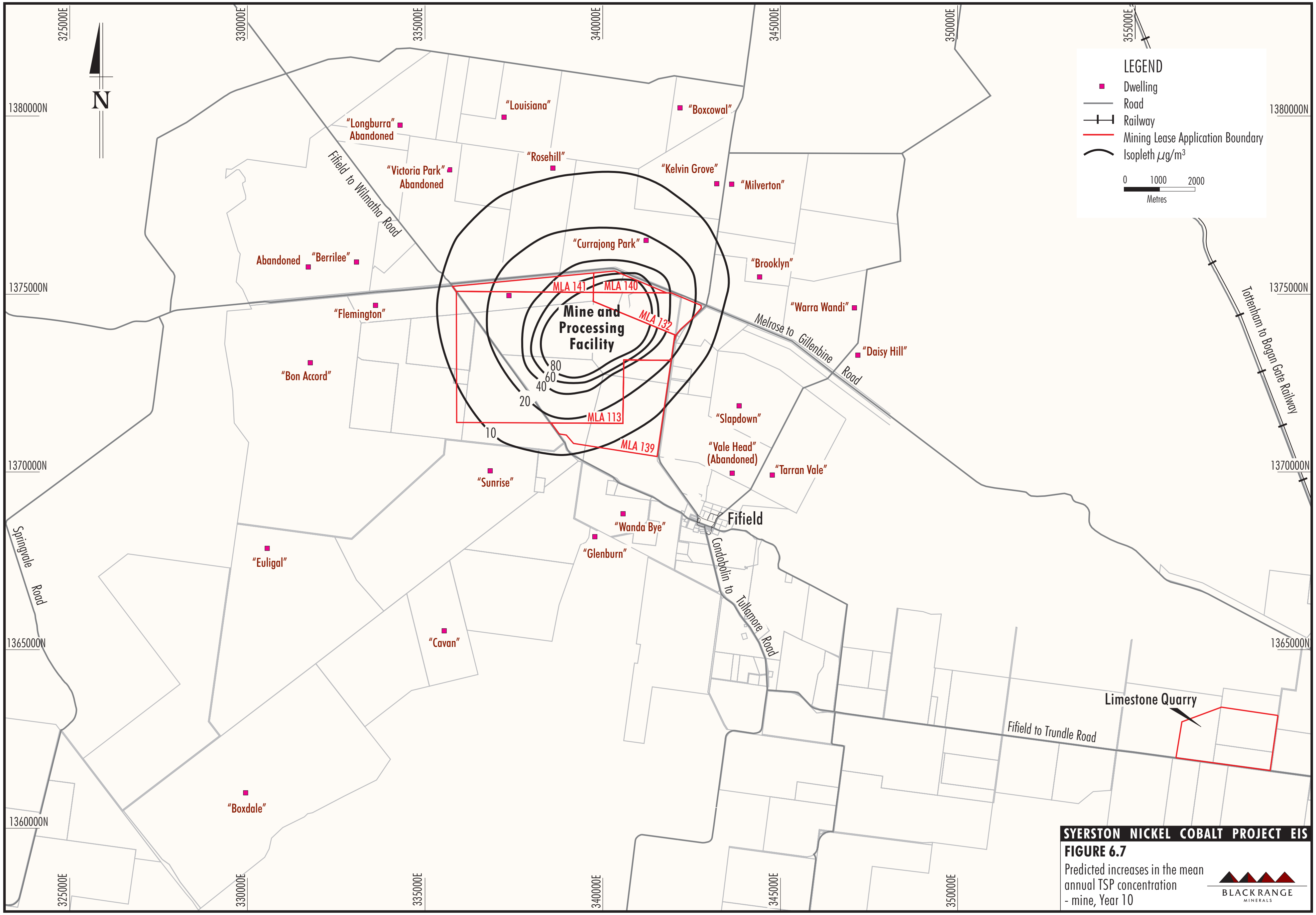


SYERSTON NICKEL COBALT PROJECT EIS

FIGURE 6.6

Predicted increases in the mean annual TSP concentration - mine, Year 5

BRM-98-01-AQ_018E



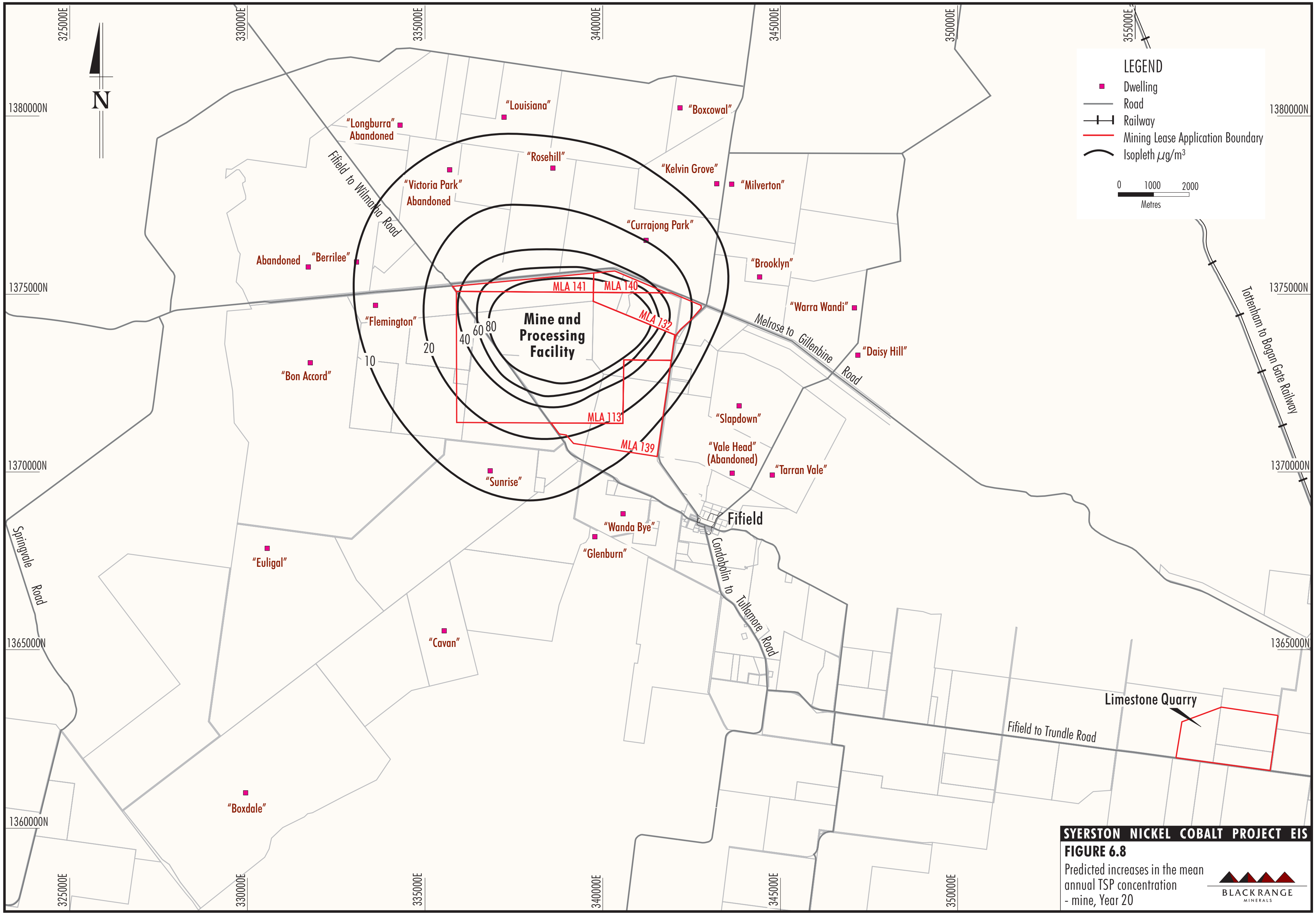
SYERSTON NICKEL COBALT PROJECT EIS

FIGURE 6.7

Predicted increases in the mean annual TSP concentration - mine, Year 10

BLACKRANGE MINERALS

BRM-98-01-AQ_019E

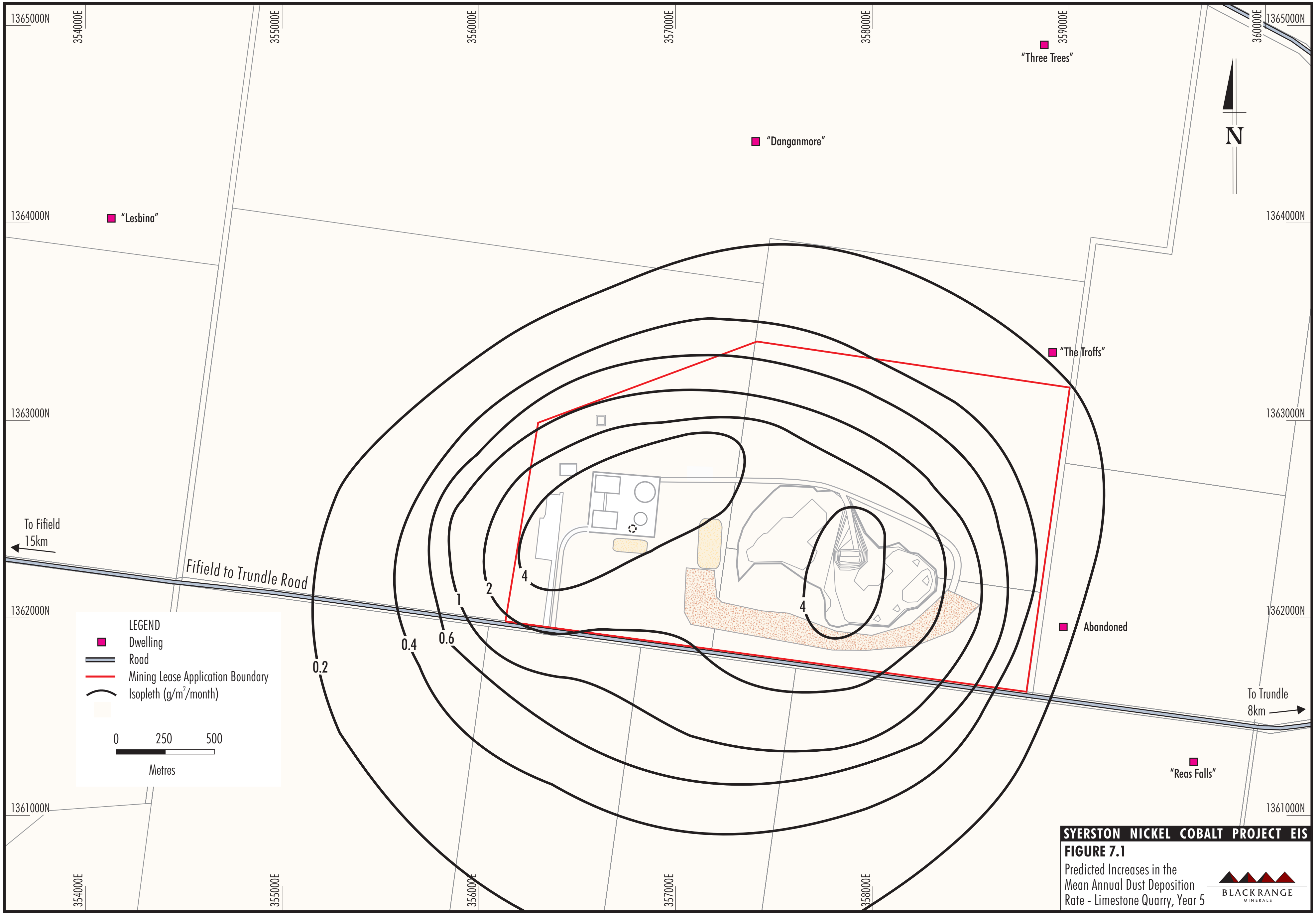


SYERSTON NICKEL COBALT PROJECT EIS

FIGURE 6.8

Predicted increases in the mean annual TSP concentration - mine, Year 20

BRM-98-01-AQ_021E

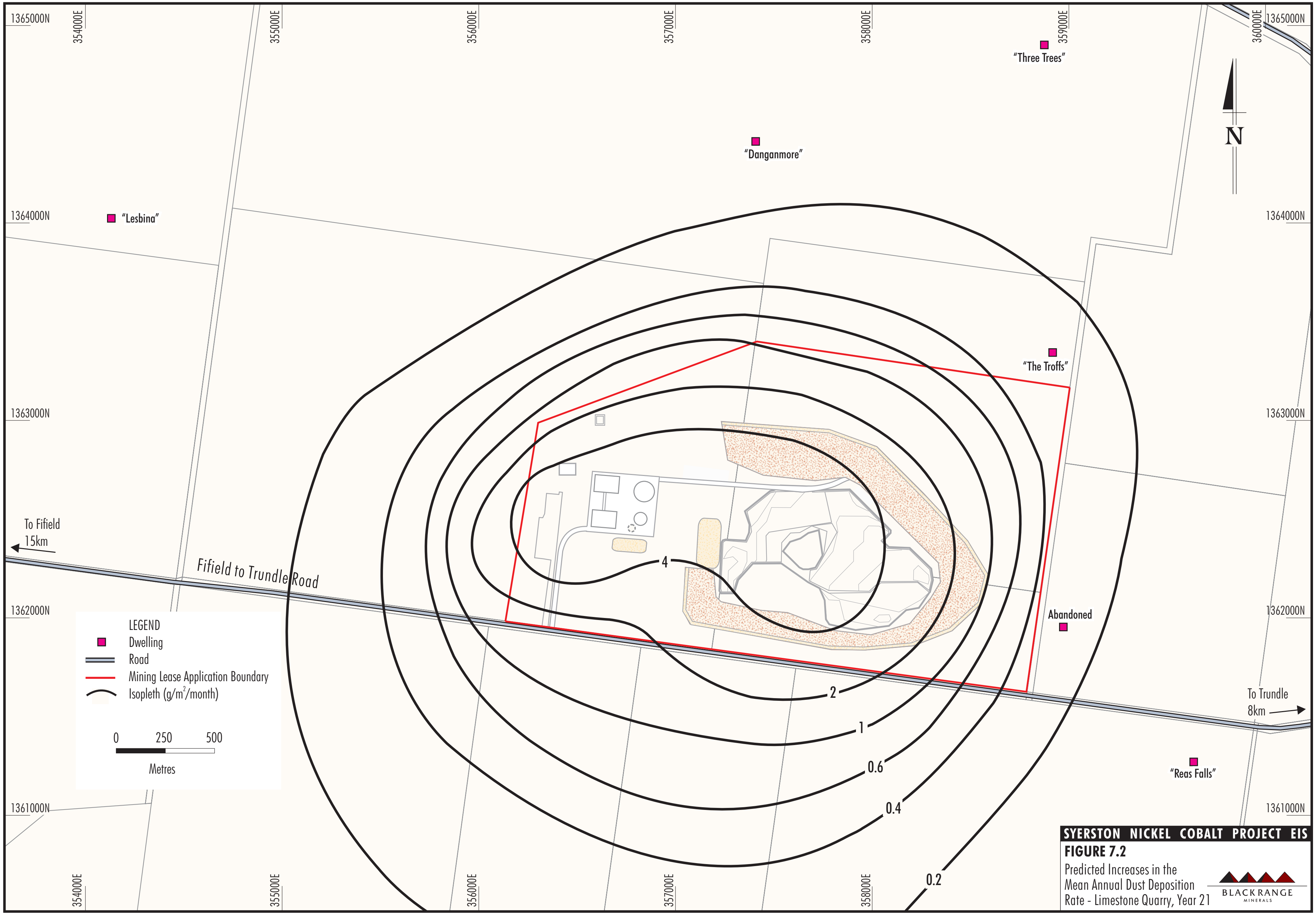


SYERSTON NICKEL COBALT PROJECT EIS

FIGURE 7.1

Predicted Increases in the Mean Annual Dust Deposition Rate - Limestone Quarry, Year 5

BRM-98-01-AQ_009B

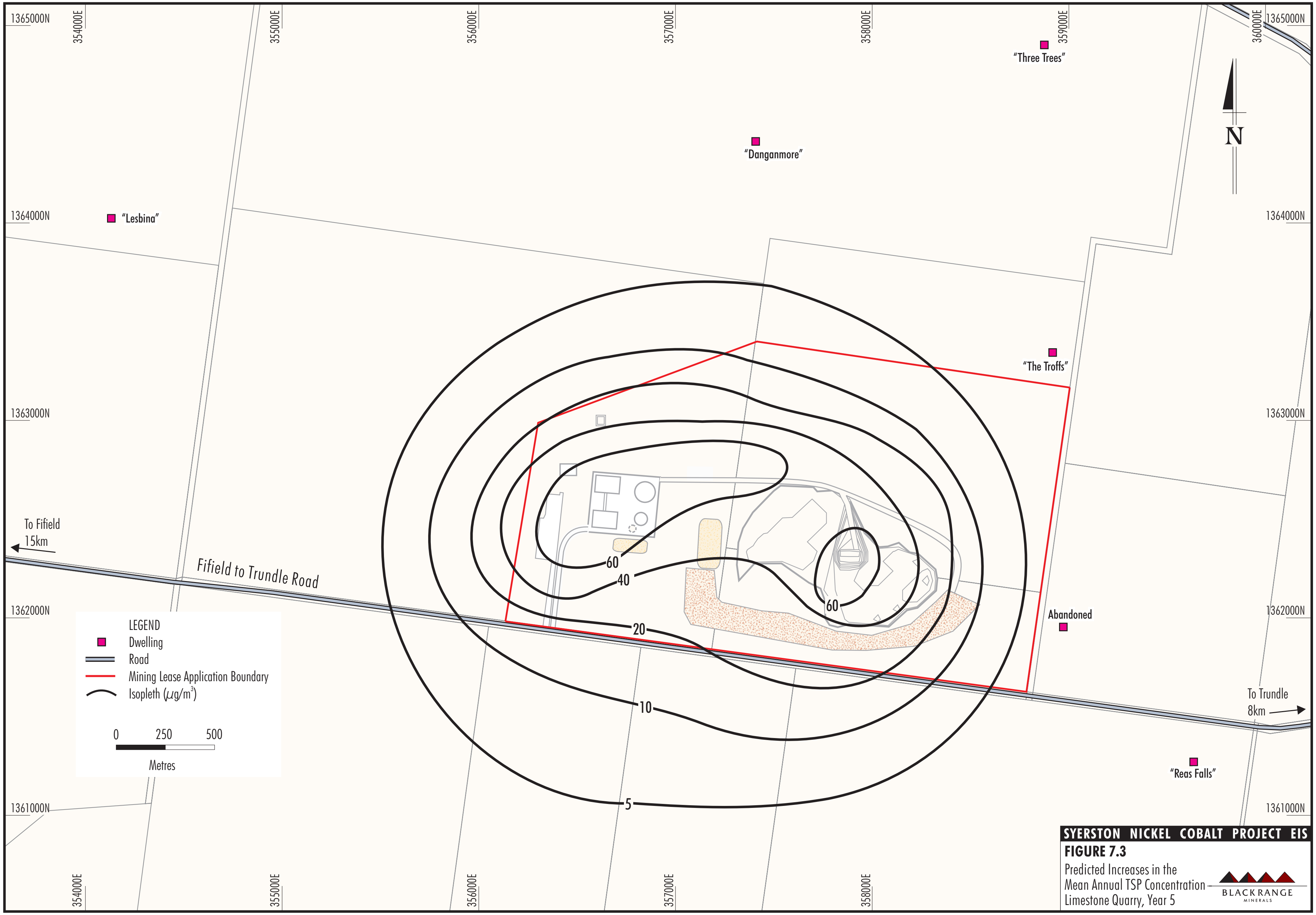


SYERSTON NICKEL COBALT PROJECT EIS

FIGURE 7.2

Predicted Increases in the Mean Annual Dust Deposition Rate - Limestone Quarry, Year 21

BRM-98-01-AQ_010B



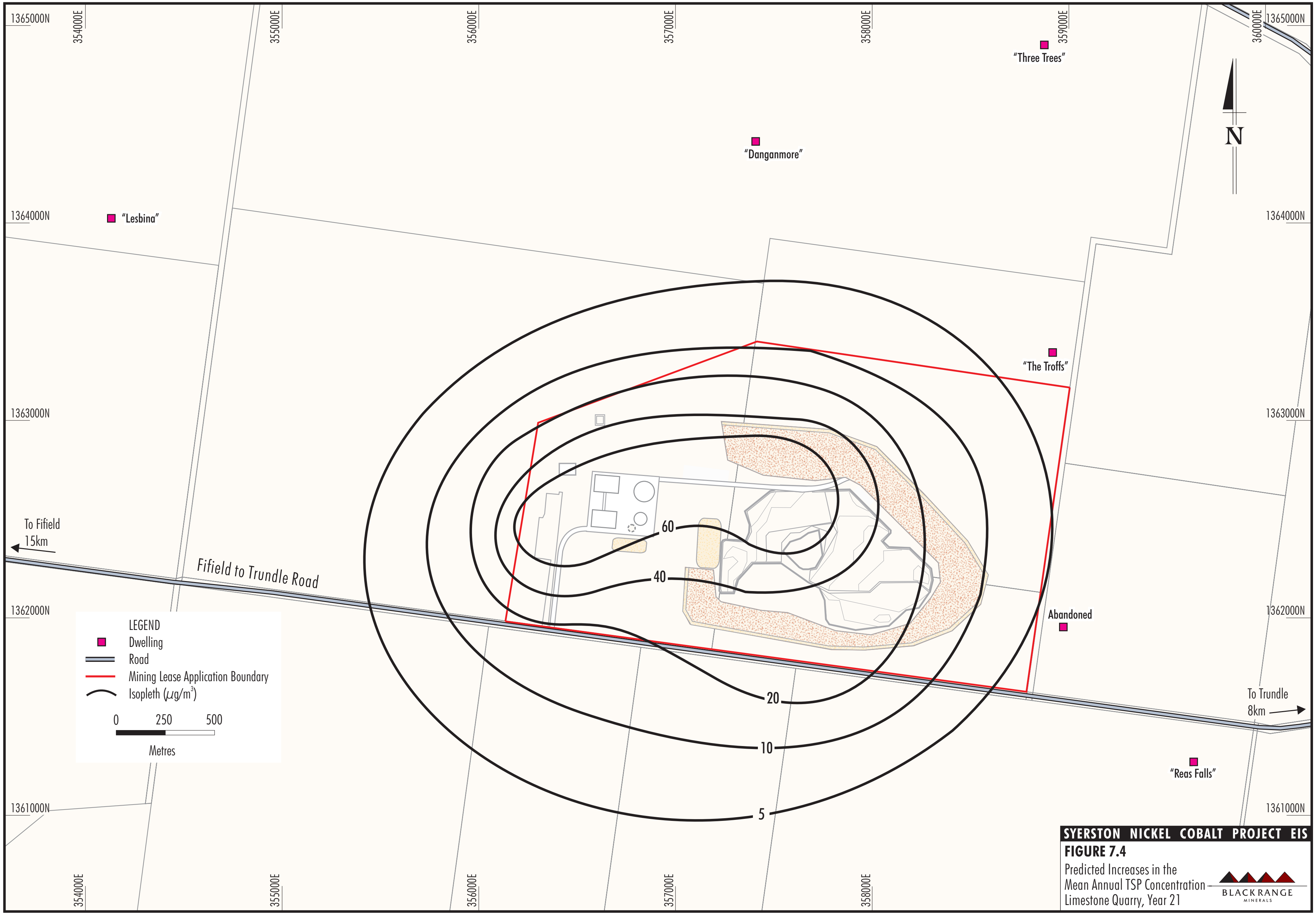
SYERSTON NICKEL COBALT PROJECT EIS

FIGURE 7.3

Predicted Increases in the
Mean Annual TSP Concentration
Limestone Quarry, Year 5

BLACK RANGE
MINERALS

BRM-98-01-AQ_011B



SYERSTON NICKEL COBALT PROJECT EIS

FIGURE 7.4

Predicted Increases in the Mean Annual TSP Concentration Limestone Quarry, Year 21

ATTACHMENTS

ATTACHMENT A.1
WIND ROSE DIAGRAMS

ANNUAL AND SEASONAL WIND ROSES FOR THE PROJECT SITE (MAY 1999 TO APRIL 2000)

ATTACHMENT A.2
NSW EPA REQUIREMENTS

AMBIENT AIR QUALITY CRITERIA FOR THE PROJECT (NSW EPA, 1998)

Table A2.1

Amenity criteria for dust

Pollutant	Goals	Agency
Dust deposition rates	4 g/m^2/month (annual average)	SPCC / EPA
Total Suspended Particulate (TSP)	90 $\mu g/m^3$ (annual average)	NHMRC

The proponent must give due consideration to the amenity based criteria for dust deposition as detailed in Table A.2.

Table A.2

EPA criteria for dust fallout

Existing Dust Level (g/m^2/month)	Maximum Acceptable Increase Over Existing Dust Level (g/m^2/month)	
	Residential, Suburban	Rural, Semi-Rural, Urban, Commercial and Industrial
2	2	2
3	1	2
4	0	1

Criteria Pollutants:
The regional ambient air goals for criteria pollutants are detailed in Table A.3

Table A.3

Pollutants	Goals	Agency
Sulphur dioxide	0.20 ppm (1-hour)	NEPM
Sulphur dioxide	0.08 ppm (24-hour)	NEPM
Sulphur dioxide	0.02 ppm (1-year)	NEPM
Particles as PM10	50 ug/m^3 (24-hour)	NEPM
Lead	0.50 ug/m^3 (1-year)	NEPM
Carbon monoxide	9.0 ppm (8-hour)	NEPM
Photochemical	0.10 ppm (1-hour)	NEPM
Oxidants (as ozone)	0.08 ppm (4-hour)	NEPM
Nitrogen dioxide	0.12 ppm (1-hour)	NEPM
	0.03 ppm (1-year)	NEPM

ATTACHMENT A.3
SAMPLES OF AUSPLUME INPUT DATA FILES

Not included in this copy

Available on request from
Black Range Minerals Ltd on (02) 9233 1400

ATTACHMENT A.4
DUST EMISSIONS - MINE

Table A.4.1

Dust emission factors for the mine and the source of data

OPERATION	EMISSION FACTOR	REFERENCE
Extraction		
Loading	0.025 kg/t	SPCC *et al* (1988)
Haulage	2.00 kg/km	SPCC *et al* (1988) - after watering
Grader on roads	0.615 kg/km	USEPA (1988)
Waste emplacement		
Waste dumping	0.012 kg/t	SPCC *et al* (1988)
Waste spreading, reshaping (dozer)	2.6 $s^{1.2}$ $M^{-1.3}$ --> 2.1 kg/hr (s=10%, M=10%)	USEPA (1991)
Exposed areas		
Wind erosion	0.40 kg/ha/hr	SPCC (1983)
Processing plant		
High-grade ore (ROM pad)		
Ore dumping to ROM	0.012 kg/t	SPCC *et al* (1988)
Ore reclaiming (FEL)	0.025 kg/t	SPCC *et al* (1988)
Loading to hopper (FEL)	0.02 kg/t	USEPA (1988)
Active stockpile (incl. loading to, equipment traffic, loading out, wind erosion - 2 x 12 hrs/day)	2 x 14.8 kg/ha/day	USEPA (Table 8.19.1-1)
Low-grade ore (stockpile)		
Ore dumping to stockpile	0.012 kg/t	SPCC *et al* (1988)
Active stockpile (incl. equipment traffic, wind erosion - 2 x 12 hrs/day)	2 x 14.8 kg/hr/day	USEPA (Table 8.19.1-1)
Ore reclaiming (FEL)	0.025 kg/t	SPCC *et al* (1988)
Ore haulage to ROM pad	2.0 kg/km	SPCC *et al* (1988) - after watering

Table A.4.2

Dust emission inventory for Year -1 (construction) of the mine

OPERATION	EXTENT OF OPERATION	ANNUAL EMISSION	COMMENTS
Extraction in pit area			
Waste loading (excavator)	1.185 Mtpa	29.6 t/yr	
Waste haulage to western emplacement	78 500 VKT/yr	157.0 t/yr	Average distance = 1.0 km Load = 20 t/truck Total of 0.785 Mtpa
Waste haulage to TSF area	108 000 VKT/yr	216.0 t/yr	Average distance = 2.7 km Load = 20 t/truck Total of 0.4 Mtpa
Grading of roads	5 760 km/yr	3.5 t/yr	Grader at 8 km/hr, 8 hrs/day, 90 days
		Subtotal 406.1 t/yr	
Western waste emplacement			
Haulage on emplacement	23 700 VKT/yr	47.4 t/yr	Average distance = 0.2 km Total of 1.185 Mtpa includes 0.785 Mtpa from pit and 0.4 Mtpa from evaporation ponds
Dumping	1.185 Mtpa	14.2 t/yr	
Spreading, shaping (dozer)	2080 hrs/yr	5.4 t/yr	Assumes 8 hours/day, 260 days/year
		Subtotal 67.0 t/yr	
TSF area			
Excavation	0.1 Mtpa	2.5 t/yr	
Dumping of material	1.32 Mtpa	15.8 t/yr	Total of 1.32 Mtpa includes 0.4 Mtpa from pit and 0.92 Mtpa from evaporation ponds
Construction (embankments, shaping etc.)	1500 hrs	7.8 t/yr	2 dozers for 10 hours/day, 150 days Silt = 12%, Moisture = 10%
		Subtotal 26.1 t/yr	
Evaporation ponds			
Excavation	2.5 Mtpa	62.5 t/yr	
Loading to trucks	1.97 Mtpa	49.2 t/yr	0.4 Mtpa to western

			emplacement, 0.65 Mtpa to eastern emplacement, 0.92 Mtpa to TSF
Haulage to eastern emplacement	273 000 VKT/yr	546.0 t/yr	Average distance = 4.2 km
Haulage to TSF	105 000 VKT/yr	210.0 t/yr	Average distance = 1.0 km Total of 1.05 Mtpa
Grading of roads	11 520 km/yr	7.0 t/yr	Grader at 8 km/hr, 8 hrs/day, 180 days
Construction (embankments, shaping etc.)	1500 hrs	7.8 t/yr	
		Subtotal 882.5 t/yr	
Eastern emplacement			
Haulage on emplacement	6 500 VKT/yr	13.0 t/yr	Average distance = 0.1 km
Dumping	0.65 Mtpa	7.8 t/yr	
Spreading, shaping (dozer)	1040 hrs	2.7 t/yr	Assumes 8 hrs/day, 130 days
		Subtotal 23.5 t/yr	
Wind erosion			
Pit area	9 ha	31.5 t/yr	
Western waste emplacement	12 ha	42.0 t/yr	
Eastern waste emplacement	12 ha	42.0 t/yr	
TSF area	90 ha	315.4 t/yr	
Evaporation ponds	100 ha	350.4 t/yr	
		Subtotal 781.3 t/yr	
		TOTAL 2186.5 t/yr	

Table A.4.3

Dust emission inventory for Year 5 of the mine

OPERATION	EXTENT OF OPERATION	ANNUAL EMISSION	COMMENTS
Extraction			
Ore and waste loading (excavator)	9.035 Mtpa	225.9 t/yr	
Ore and waste haulage (in-pit)	105.060 VKT/yr	210.1	Average distance = 0.5 km
		Subtotal 436.0 t/yr	
Ore haulage (out-of-pit)			
High grade to stockpile and ROM pad	81 400 VKT/yr	162.9 t/yr	Average distance = 1.75 km Load = 86 t/truck Total of 2.00 Mtpa
Grading of roads	49 920 km/yr	30.7 t/yr	3 graders at 8 km/hr, 8 hrs/day, 260 days
		Subtotal 193.6 t/yr	
Processing plant			
Low grade ore			
Passive stockpile (wind erosion)	37.5 ha	131.4 t/yr	
		Subtotal 131.4 t/yr	
Processing plant			
High grade ore			
Dumping	2.0 Mtpa	24.0 t/yr	Includes stockpile and ROM pad
Active stockpile (maintenance, wind erosion)	49 ha	529.4 t/yr	Includes equipment traffic Area = 49.0 ha, 24 hrs/day, 365 days/year
Reclaiming from ROM pad	2.00 Mtpa	50.0 t/yr	Total ore = 2.00 Mtpa
Loading to hopper	2.00 Mtpa	20.0 t/yr	
		Subtotal 623.4 t/yr	
Waste emplacement			
	102 250 VKT/yr	204.5 t/yr	Average distance = 0.25 km

Haulage to emplacement			(in the east) Average distance = 1.0 km (in the west) Load = 86 t truck Total of 7.035 Mtpa
Haulage on emplacement	130 880 VKT/yr	261.8 t/yr	Average distance = 0.8 km
Dumping	7.035 Mtpa	84.4 t/yr	
Spreading, shaping (dozer)	8760 hrs/yr	18.4 t/yr	Assumes 2 x 12 hours/day,. 365 days/year
		Subtotal 569.1 t/yr	
Wind erosion			
Waste emplacement	90 ha	315.4 t/yr	
		Subtotal 315.4 t/yr	
		TOTAL 2268.9 t/yr	

Table A.4.4

Dust emission inventory for Year 10 of the mine

OPERATION	EXTENT OF OPERATION	ANNUAL EMISSION	COMMENTS
Extraction			
Ore and waste loading (excavator)	6.85 Mtpa	171.3 t/yr	
Ore and waste haulage (in-pit)	238 950 VKT/yr	477.9	Average distance = 1.5 km
		Subtotal 649.2 t/yr	
Ore haulage (out-of-pit)			
Low grade to stockpile	45 000 VKT/yr	90.0 t/yr	Average distance = 2.25 km Load = 86 t/truck Total of 0.86 Mtpa
High grade to ROM pad	38 080 VKT/yr	76.2 t/yr	Average distance = 1.25 km Total of 1.31 Mtpa
Grading of roads	33 280 km/yr	20.5 t/yr	2 graders at 8 km/hr, 8 hrs/day, 260 days
		Subtotal 186.7 t/yr	
Processing plant			
Low grade ore			
Dump to stockpile	0.86 Mtpa	10.3 t/yr	
Active stockpile (maintenance, wind erosion) - 12 hrs/day		405.1 t/yr	Estimated total area = 75 ha, 12 hrs/day, 365 days
Reclaiming	0.86 Mtpa	21.5 t/yr	
Haulage to ROM pad	30 000 VKT/yr	60.0 t/yr	Average distance = 1.5 km Load = 86 t/truck
Dumping to ROM pad	0.86 Mtpa	10.3 t/yr	
		Subtotal 507.2 t/yr	
Processing plant			

High grade ore			
Dump to ROM pad	1.31 Mtpa	15.7 t/yr	Assumes 50% via ROM pad
Active ROM stockpile (maintenance, wind erosion)		97.2 t/yr	Includes equipment traffic Area = 9.0 ha, 24 hrs/day, 365 days/year
Reclaiming from ROM pad	2.17 Mtpa	54.3 t/yr	Total ore = 2.17 Mtpa
Loading to hopper	2.17 Mtpa	21.7t/yr	Includes both high and low grade
		Subtotal 188.9 t/yr	
Waste emplacement			
Haulage to emplacement	125 170 VKT/yr	250.3 t/yr	Average distance = 1.15 km Load = 86 t truck Total of 4.68 Mtpa
Haulage on emplacement	187 740 VKT/yr	375.5 t/yr	Average distance = 1.5 km
Dumping	4.68 Mtpa	56.2 t/yr	
Spreading, shaping (dozer)	8760 hrs/yr	18.4 t/yr	Assumes 2 x 12 hours/day,. 365 days/year
		Subtotal 700.4 t/yr	
Wind erosion			
Waste emplacement (eastern)	75 ha	262.8 t/yr	
Waste emplacement (western) - inactive	20 ha	70.1 t/yr	
		Subtotal 332.9 t/yr	
		TOTAL 2565.3 t/yr	

Table A.4.5

Dust emission inventory for Year 20 of the mine

OPERATION	EXTENT OF OPERATION	ANNUAL EMISSION	COMMENTS
Extraction			
Ore and waste loading (excavator)	10.48 Mtpa	262.0 t/yr	
Ore and waste haulage (in-pit)	243 760 VKT/yr	487.5	Average distance = 1.0 km Load = 86 t/truck
		Subtotal 749.5 t/yr	
Ore haulage (out-of-pit)			
Low grade to stockpile	46 560 VKT/yr	93.1 t/yr	Average distance = 1.25 km Load = 86 t/truck Total of 1.60 Mtpa
High grade to ROM pad	9 380 VKT/yr	18.8 t/yr	Average distance = 1.0 km Total of 0.40 Mtpa
Grading of roads	49 920 km/yr	30.7 t/yr	3 graders at 8 km/hr, 8 hrs/day, 260 days
		Subtotal 142.6 t/yr	
Processing plant			
Low grade ore			
Dump to stockpile	1.60 Mtpa	19.2 t/yr	
Active stockpile (maintenance, wind erosion) - 24 hrs/day		810.3 t/yr	Estimated total area = 75 ha, 24 hrs/day, 365 days
Reclaiming	1.60 Mtpa	40.0 t/yr	
Haulage to ROM pad	55 870 VKT/yr	111.7 t/yr	Average distance = 1.5 km Load = 86 t/truck
Dumping to ROM pad	1.60 Mtpa	19.2 t/yr	
		Subtotal 1000.4 t/yr	
Processing plant			
High-grade ore			

Dump to ROM pad	0.40 Mtpa	4.8 t/yr	Assumes 50% via ROM pad
Active ROM stockpile (maintenance, wind erosion)		97.2 t/yr	Includes equipment traffic Area = 9.0 ha, 24 hrs/day, 365 days/year
Reclaiming from ROM pad	2.00 Mtpa	50.1 t/yr	Total ore = 2.00 Mtpa
Loading to hopper	2.00 Mtpa	20.0 t/yr	Includes both high and low grade
		Subtotal 172.1 t/yr	
Waste emplacement			
Haulage to emplacement	394 280 VKT/yr	788.6 t/yr	Average distance = 2.0 km Load = 86 t/truck Total of 8.48 Mtpa
Haulage on emplacement	197 140 VKT/yr	394.3 t/yr	Average distance = 1.0 km
Dumping	8.48 Mtpa	101.7t/yr	
Spreading, shaping (dozer)	8760 hrs/yr	18.4 t/yr	Assumes 2 x 12 hours/day, 365 days/year
		Subtotal 1303.0 t/yr	
Wind erosion			
Waste emplacement	108.75 ha	381.1 t/yr	
		Subtotal 381.1 t/yr	
		TOTAL 3748.7 t/yr	

ATTACHMENT A.5
DUST EMISSIONS – LIMESTONE QUARRY

Table A.5.1

Dust emission factors for the limestone quarry and the source of data

OPERATION	EMISSION FACTOR	REFERENCE
<u>Extraction</u>		
Drilling	0.6kg/hole	SPCC (1983)
Blasting	$344\ A^{0.8}\ M^{-1.9}\ d^{-1.8}$	USEPA (1985)
Loading (FEL)	0.025 kg/t	SPCC *et al* (1988)
Haulage	2.00 kg/km	SPCC *et al* (1988) - after watering
Grader on roads	0.615 kg/km	USEPA (1988)
<u>Waste emplacement</u>		
Waste dumping	0.012 kg/t	SPCC *et al* (1988)
Waste spreading, reshaping (dozer)	$2.6\ s^{1.2}\ M^{-1.3}$ --> 2.1 kg/hr (s=10%, M=10%)	USEPA (1991)
<u>Exposed areas</u>		
Wind erosion	0.40 kg/ha/hr	SPCC (1983)
<u>Processing plant</u>		
Ore dumping to ROM	0.012 kg/t	SPCC *et al* (1988)
Ore reclaiming (FEL)	0.025 kg/t	SPCC *et al* (1988)
Loading to crusher (FEL)	0.02 kg/t	USEPA
Crushing (moisture > 1.5%)	0.009 kg/t	USEPA (Table 8.19.1-1)
Screening	0.08 kg/t	USEPA (Table 8.19.1-1)
Conveyor transport	0.0017 kg/t	USEPA (Table 8.19.2-2)
Transfer points	0.17×10^{-3} kg/t	USEPA (Table 8.19.2-2)
Active stockpile (incl. loading to, equipment traffic, loading out, wind erosion - 12 hrs/day)	14.8 kg/ha/day	USEPA (Table 8.19.1-1)
Loading to trucks	0.028 kg/t	USEPA (Table 8.19.1-1)
Haulage of product by road train.	2 x 2.0 kg/km	SPCC *et al* (1988) - after watering

Table A.5.2

Dust emission inventory for Year 5 of the limestone quarry

OPERATION	EXTENT OF OPERATION	ANNUAL EMISSION	COMMENTS
<u>Extraction</u>			
Ore and waste drilling	2125 holes/yr	1.3 t/yr	Bench height = 15 m, 125 holes/blast at 3m x 3m
Ore and waste blasting	17 blasts/yr	0.2 t/yr	9.2 kg/blast Area of blast = 1130 m2
Ore and waste loading	696 838 tpa	17.4 t/yr	
Ore haulage for processing	42 000 VKT/yr	84.0 t/yr	Average distance = 1.5 km Load = 40 t/truck Total of 560 000 tpa of high grade
Grading of roads	4 160 km/yr	2.6 t/yr	Assumes 8 hrs/day at 8 km/hr, 65 days/year
		<u>Subtotal 105.5 t/yr</u>	
<u>Processing plant</u>			
<u>High grade ore</u>			
Dump to ROM pad	280 000 tpa	3.4 t/yr	Assumes 50% via ROM pad
Active ROM stockpile (maintenance, wind erosion)		2.9 t/yr	Includes equipment traffic Area = 0.75 ha, 260 days/year
Reclaiming from ROM pad	280 000 tpa	7.0 t/yr	Assumes 50% via ROM pad
Ore dumping (to crusher)	560 000 tpa	5.6 t/yr	Includes 280 000 tpa from ROM stockpile
Primary crushing and screening	560 000 tpa	49.8 t/yr	Fogging sprays, 50% reduction in emission
Secondary crushing and screening	420 000 tpa	37.4 t/yr	Assumes 75% for secondary crushing 50% reduction in emission
Conveying to product stockpile	560 000 tpa	1.3 t/yr	Includes 3 transfers
Active product stockpile (maintenance, wind erosion)		1.9 t/yr	Area = 0.50 ha 260 days/year
	560 000 tpa	15.7 t/yr	

Load product to trucks	20 160 VKT/yr		Distance = 0.9 km 50 t trucks (road train) Double emission for road train
Trucks on access road			
		Subtotal 125.0 t/yr	
Waste emplacement			
Low grade and waste	13 680 VKT/yr	27.4 t/yr	Average distance = 2.0 km Load = 160 t truck Total of 136 838 tpa of low grade and waste
Haulage to emplacement			
	136 838 tpa	1.6 t/yr	
Dumping	1040 hrs/yr	2.2 t/yr	Assumes 4 hours/day, 260 days/year
Spreading, shaping (dozer)		Subtotal 31.2 t/yr	
Wind erosion	10.5 ha	36.8 t/yr	
Pit area	27.5 ha	96.4 t/yr	
Waste emplacement	10.5 ha	36.8 t/yr	
Processing area		Subtotal 170.0 t/yr	
		TOTAL 431.7 t/yr	

Table A.5.3

Dust emission inventory for Year 21 of the limestone quarry

OPERATION	EXTENT OF OPERATION	ANNUAL EMISSION	COMMENTS
Extraction			
Ore and waste drilling	2080 holes/yr	1.3 t/yr	Bench height = 15 m, 173 holes/blast at 3m x 3m
Ore and waste blasting	12 blasts/yr	0.2 t/yr	11.9 kg/blast Area of blast = 1550 m2
Ore and waste loading	696 838 tpa	17.4 t/yr	
Ore haulage for processing	42 000 VKT/yr	84.0 t/yr	Average distance = 1.5 km Load = 40 t/truck Total of 560 000 tpa of high grade
Grading of roads	8 320 km/yr	5.1 t/yr	Assumes 8 hrs/day at 8 km/hr, 130 days/year
		Subtotal 108.0 t/yr	
Processing plant			
High grade ore			
Dump to ROM pad	280 000 tpa	3.4 t/yr	Assumes 50% via ROM pad
Active ROM stockpile (maintenance, wind erosion)		2.9 t/yr	Includes equipment traffic Area = 0.75 ha, 260 days/year
Reclaiming from ROM pad	280 000 tpa	7.0 t/yr	Assumes 50% via ROM pad
Ore dumping (to crusher)	560 000 tpa	5.6 t/yr	Includes 280 000 tpa from ROM stockpile
Primary crushing and screening	560 000 tpa	49.8 t/yr	Fogging sprays, 50% reduction in emission
Secondary crushing and screening	420 000 tpa	37.4 t/yr	Assumes 75% for secondary crushing 50% reduction in emission
Conveying to product stockpile	560 000 tpa	1.3 t/yr	Includes 3 transfers
Active product stockpile		1.9 t/yr	Area = 0.50 ha 260 days/year

(maintenance, wind erosion)	560 000 tpa	15.7 t/yr	
Load product to trucks	20 160 VKT/yr		Distance = 0.9 km 50 t trucks (road train) Double emission for road train
Trucks on access road			
		Subtotal 125.0 t/yr	
Waste emplacement			
Low grade and waste	15 720 VKT/yr	31.4 t/yr	Average distance = 2.3 km Load = 160 t truck Total of 136 838 tpa of low grade and waste
Haulage to emplacement			
	136 838 tpa	1.6 t/yr	
Dumping	1040 hrs/yr	2.2 t/yr	Assumes 4 hours/day, 260 days/year
Spreading, shaping (dozer)		Subtotal 35.2 t/yr	
Wind erosion	22.5 ha	77.1 t/yr	
Pit area	55.5 ha	190.1 t/yr	
Waste emplacement	10.5 ha	36.8 t/yr	
Processing area		Subtotal 304.0 t/yr	
		TOTAL 572.2 t/yr	

ATTACHMENT A.6
SAMPLES OF ISC3 DATA FILES

Attachment A.6.1 – Mine (Year 20)
Attachment A6.2 – Limestone Quarry

Not included in this copy
Available on request from
Black Range Minerals Ltd on (02) 9233 1400

PRELIMINARY HAZARD ASSESSMENT FOR THE SYERSTON NICKEL – COBALT PROJECT FIFIELD, NSW

Revision I

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15 September 2000

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Preliminary Hazard Assessment for the Syerston Nickel – Cobalt Project, Fifield, NSW

Disclaimer

This report was prepared by SHE Pacific Pty Ltd (SHE Pacific) as an account of work for Resource Strategies Pty Ltd (on behalf of Black Range Minerals Ltd). The material in it reflects SHE Pacific's best judgement in the light of the information available to it at the time of preparation. However, as SHE Pacific cannot control the conditions under which this report may be used, SHE Pacific and its related corporations will not be responsible for damages of any nature resulting from use of or reliance upon this report. SHE Pacific's responsibility for advice given is subject to the terms of engagement with Resource Strategies Pty Ltd.

Rev	Date	Description	Reviewed By	Authorised By
A	9/6/00	Draft for Comment	J Polich	I Lake
B	4/7/00	Resource Strategies Comments Included	J Polich	I Lake
C	17/7/00	Black Range Minerals Comments Included	J Polich	I Lake
D	15/9/00	General Revision	J Polich	I Lake

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EXECUTIVE SUMMARY

Introduction

The objective of this Preliminary Hazard Analysis (PHA) is to ensure a comprehensive understanding exists of the hazards and risks associated with the operation of the proposed nickel and cobalt extraction plant at Syerston, NSW, (owned by Black Range Minerals Ltd) and that adequate safeguards are proposed to mitigate these risks.

As part of the PHA, a quantitative risk assessment was undertaken and the calculated risk levels compared with the guidelines and criteria established by the NSW Department of Urban Affairs and Planning (DUAP).

To assess the risk levels, the following well established methodology has been used:

- ↓ Identification of hazards. All operations must be considered for the potential to harm people, equipment and the environment
- ↓ Evaluation of the consequences of the hazards
- ↓ Evaluation of the likelihood of hazardous events
- ↓ Determination of risk from all hazardous events
- ↓ Assessment of risk against established criteria
- ↓ Identification and evaluation of risk reduction measures

Summary of Findings

The analysis of the Syerston Nickel Cobalt Project shows that the proposed operations pose low levels of risk to the surrounding areas. The main reason for the low calculated off-site risk levels is the large distances from the Project hazardous operations to the nearest site boundaries.

For example, the nearest mine site boundary (in the west direction) from the processing plant is approximately 1 kilometre away. All other boundaries in the north, east and south directions are in excess of 1.75 km.

Also, whilst risk is calculated for the nearest off-site location, however, the nearest residence in the westerly direction from the mine site is more than 3 kilometres away from the processing plant.

For most hazardous events modelled during this study, little or no impact could be expected at such large distances. Therefore, the approach taken within this PHA is to analyse the significant events likely to have an impact beyond the distance to the site boundaries and calculate the corresponding risk levels. The hazard identification, consequence analysis and frequency analysis in this PHA show that significant events with the potential for off-site effects are limited to the mine site.

Generally, a conservative approach has been taken with the consequence modelling work. In particular, for toxic gas releases, conservative modelling parameters have been used (eg surface terrain roughness being that of flat rural land – no allowance for dispersion due to plant structures etc). Additionally, the effect prediction methods implemented (eg equations (probits) to predict fatality probability) were selected to fit the available data conservatively.

The proposed Project includes the use of internationally recognised standards, proven quality construction companies, as well as the implementation of a robust safety management system. No mitigation of risk due to this approach has been included in the analysis within this PHA. The approach taken by Black Range Minerals is consistent with current 'best practice' within industry and will serve to mitigate the risk of the identified hazardous events within this analysis.

Individual Fatality Risk

Off-site individual fatality risk at the nearest mine site boundary was found to be due to one event only; a major release of sulphur dioxide. The calculated risk value of 1.6 pmpy (ie risk of an off-site fatality per million per year) compares favourably to the DUAP target values. Given the accuracy of the modelling packages available over such a large distance with the conservative approach taken in the assessment, this result confirms the low off-site individual fatality risk levels expected from the plant.

Toxic Injury and Irritation Risk

The total frequency of exceeding off-site irritation toxic risk levels for all identified gas releases from the mine site was calculated to be 30 pmpy. For a rural location, this risk value is relatively low.

The frequency of exceeding off-site toxic injury risk levels for all identified gas releases from the mine site was calculated to be 23 pmpy. Again, given the accuracy of the modelling over such a large distance and the conservative approach adopted in the analysis (ie no allowance for increased dispersion due to plant structures, selection of event frequencies etc) and the low likelihood of people at the site boundary who cannot escape in the event of a gas release, then the risk of off-site toxic injury is considered low.

Fire and Explosion Injury Risk

For the off-site risk of injury from fires and explosions, there is no credible likelihood of exceeding either 4.7 kW/m^2 or 7 kPa at any site boundaries. Therefore, off-site injury risk from fires and explosions is considered negligible.

Societal Risk

For this particular study, only one incident (catastrophic failure of a vessel or pipe within the sulphuric acid plant) was identified that could potentially cause fatality off-site. Given the rural nature of the land with the sparse locations of the nearby farm houses, the calculation of societal risk is not justified, ie the likelihood of multiple fatalities is very low. Given that only one incident was identified for off-site fatality risk then the individual fatality off-site risk calculation is the most appropriate for this site. This showed a low level of off-site fatality risk. Hence, no societal risk calculations are warranted or performed.

Cumulative Risk

Cumulative risk is the summation of calculated levels of risk from all hazardous facilities within a particular area. Given the rural location (ie no nearby hazardous industries) and the calculated low levels of individual fatality risk posed by the proposed facility at the site boundaries, then assessment of cumulative risk is unnecessary for this proposal.

Risk of Domino (or Knock-on) Effects

The proposed site layout includes generous separation distances between most process areas, hence the likelihood of propagation due to thermal radiation or overpressure from fires or explosions has been found to be low. Another minor risk is the likelihood of propagation by events such as earthquakes or aircraft crashes. However, given the proposed site location, these types of events are very unlikely, hence risk is also low.

Irrespective of the mitigation afforded by the generous plant layout etc, should a domino incident occur, for most incidents the effects are largely contained on site. Should an event occur due to propagation with off-site effects then, again, the analysis for off-site irritation, injury and fatality still holds. As shown, there are low off-site levels of individual fatality risk, irritation risk and injury risk. Therefore, propagation (or knock-on or domino) type incidents from the facility pose low levels of risk.

Risk to the Biophysical Environment

Given the limited number of events (large effect, short term releases) that can occur at this site with off-site impacts (due to the large distance to the nearest site boundary) and the rural nature of the surrounding area, the risk to people and other biological groups (animals, plants etc) is low. Whilst off-site effect can be expected if a major release were to occur, there are no identified whole systems or populations which are at unacceptable levels of risk due to the potentially hazardous events reviewed in this PHA.

Transport Risk

All classified dangerous goods will be transported according to the regulations in the Australian Code for the Transport of Dangerous Goods by Road and Rail. Whilst there will be an increase to existing traffic levels through the delivery of materials to, and from, the mine, quarry and rail siding sites, there are no identified departures from these regulations for the proposed development. Hence, there were no transport types identified that would pose unacceptable risk to surrounding land uses. Transport routes are assessed elsewhere in the Environmental Impact Statement for the project.

Risk Reduction Measures

The dominant contributor to risk is a major gas release from the sulphuric acid plant. All other scenarios that have an effect at the nearest site boundary are minor contributors to risk only.

The development proposal includes the use of internationally recognised standards, proven quality construction companies, as well as the implementation of a robust safety management system. No mitigation of risk due to this approach has been included in the analysis within this PHA. The approach taken by Black Range Minerals is consistent with current ‘best practice’ within industry and will serve to mitigate the risk of the identified hazardous events within this analysis.

Therefore, no further safety measures are recommended at this stage. Should the project proceed, then the details of the plant design and operation should be reviewed in the Final Hazards Analysis (typically a DUAP Condition of Consent) as it is possible that risk mitigation is justifiable and the effects at the nearest site boundary (ie particularly due to gas releases from the sulphuric acid plant) are less than those predicted in this PHA.

Recommendations

As shown in this PHA, the events likely to have off-site impacts involve large releases of hydrogen sulphide or sulphur dioxide. However, given that the proposed nickel and cobalt extraction plant will represent a modern design with the technical controls and safeguards expected of a ‘state-of-the-art’ facility (and a robust safety management system will be implemented), then the risk of hazardous events occurring (with off-site impacts) is considered low.

Therefore no specific recommendations are made from this study other than, should the project proceed, then the details of the plant design and operation should be reviewed in the HAZOP and Final Hazards Analysis as it is possible that further risk mitigation measures are justifiable. Specifically, these studies should address the hydrogen sulphide and sulphur dioxide isolation systems, emergency procedures and any additional release preventative measures.

REPORT

1 INTRODUCTION

Black Range Minerals Ltd (Black Range) is proposing to mine an average of 2 million tonnes per annum of nickel cobalt laterite ore and establish a nickel and cobalt extraction plant at Syerston, 80km north-west of Parkes in New South Wales. In addition to a proposed mine site, a limestone quarry, rail siding, gas pipeline, water pipeline, borefield and road upgrade are proposed. These components combine to make up the Syerston Nickel Cobalt Project (the Project). Locations of the Project components are shown on Figure 1.

A production capacity of approximately 25 000 tonnes per annum of metal with up to 20 000 tonnes per annum of nickel and 5 000 tonnes per annum of cobalt would be produced.

An Environmental Impact Statement (EIS) for the proposed Project is required by the regulatory authorities to assess potential environmental impacts on the existing local and state areas and facilities. Part of the EIS is an assessment of the imposed levels of risk due to the hazardous nature of the proposed processes. This assessment is performed as a Preliminary Hazard Assessment (PHA) as required by the Department of Urban Affairs and Planning (DUAP). The DUAP Hazardous Industry Planning Advisory Papers No. 4 (Ref 1) and No. 6 (Ref 2) provide the guidelines for performing such assessments.

SHE Pacific Pty Ltd (SHE Pacific) was appointed by Resource Strategies Pty Ltd on behalf of Black Range Minerals Ltd to conduct this PHA on the proposed Project and prepare the study report.

1.1 Objectives and Scope

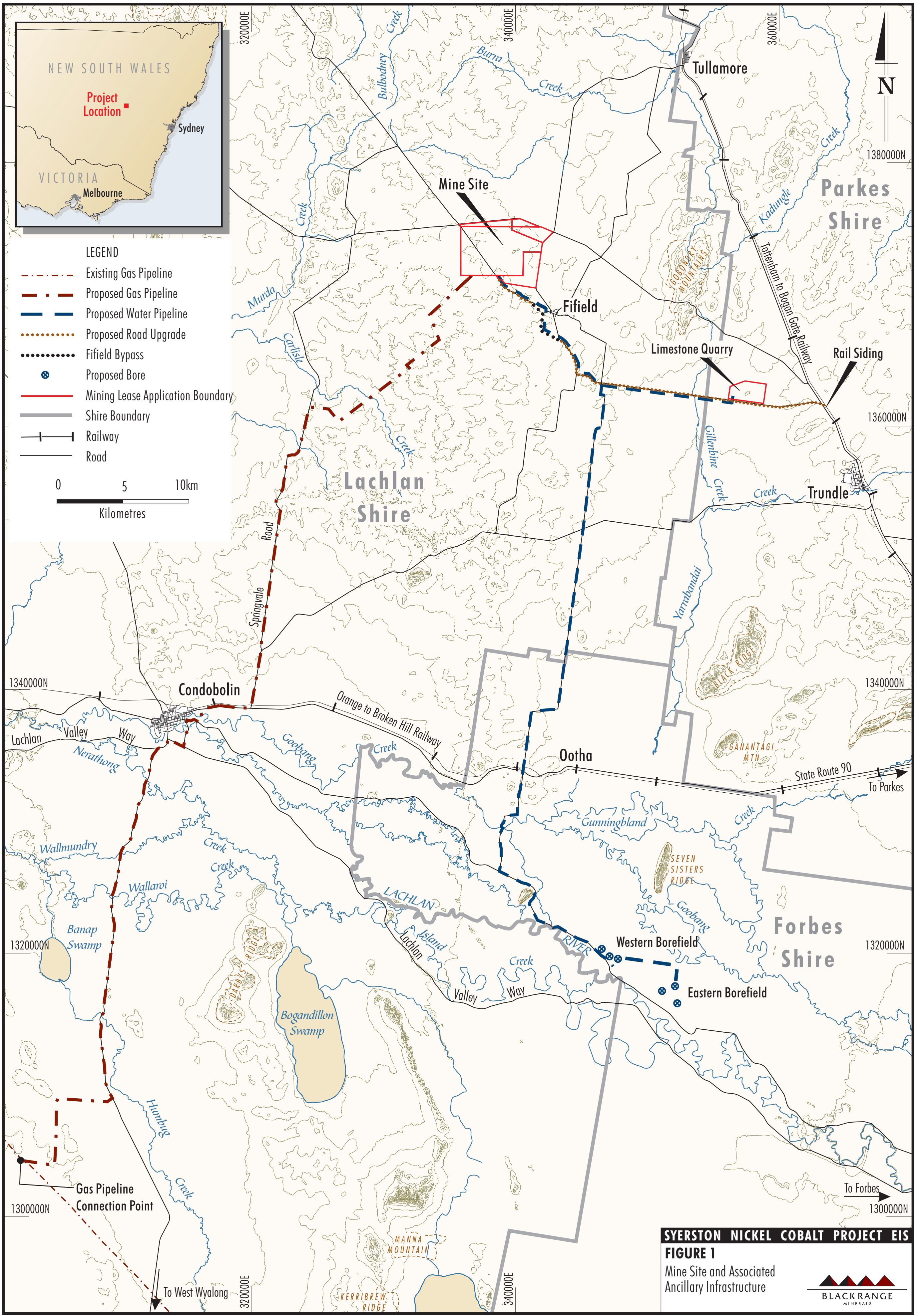
The main aims of this study are to:

↓ Carry out a PHA of the proposed nickel and cobalt extraction plant for submission to the DUAP, as part of the Environmental Impact Statement

↓ Evaluate the level of risk from the proposed development to surrounding land use and compare the calculated risk levels with the risk guidelines published by the DUAP

↓ Assess the implications for the cumulative risk associated with the proposed nickel and cobalt extraction plant

↓ Submit recommendations to the proponent to ensure that the proposed nickel and cobalt extraction plant is designed, operated and maintained at acceptable levels of safety and that effective safety management systems are implemented at the site



SYERSTON NICKEL COBALT PROJECT EIS

FIGURE 1

Mine Site and Associated Ancillary Infrastructure

BRM-98-01-Risk_002D

1.2 Study Methodology

The hazard analysis technique used for assessing the risk to the public or operating personnel involves the following steps:

- ↓ Identification of the hazards associated with the proposed nickel and cobalt extraction plant, including those which may potentially injure people or damage the environment
- ↓ Estimation of the magnitude of the consequences for these incidents
- ↓ Estimation of the frequency with which these incidents may occur
- ↓ Estimation of risk by combining the frequency of the event occurring with the probability of an undesired consequence
- ↓ Assessment of the risk estimated against the guidelines and criteria relevant to the proposal, in this case those set by the NSW Department of Urban Affairs and Planning.

The basic approach to evaluating and improving technical safety in this report is per the methods detailed in Ref 2.

1.3 Criteria

The NSW Department of Urban Affairs and Planning specifies the maximum acceptable risk levels for a new installation to which members of the public can be exposed. Criteria exist for both fatality risks and injury risks to an exposed individual. These criteria are published in the Department's Hazardous Industry Planning Advisory Paper No. 4 (Ref 1) and relate to a hypothetical person located permanently at a location. Injury criteria are expressed as the frequency of exceeding certain threshold levels of fire radiation, explosion overpressure or toxic gas concentrations. Table 1 summarises the DUAP criteria, against which the risks from the Project will be assessed.

Table 1 – DUAP Risk Criteria

TYPE OF RISK	ACCEPTABLE MAXIMUM pmpy*
Fatality – hospitals, schools, child care facilities, old aged housing	0.5
Fatality – residential area	1
Fatality – commercial developments, retail centres, offices and entertainment centres	5
Fatality – sporting complexes and active open space	10
Fatality – industrial sites	50
Injury – exceed radiant heat levels of 4.7 kW/m^2 or explosion overpressures of 7 kPa in residential areas	50
Damage – exceed radiant heat levels of 23 kW/m^2 or explosion overpressures of 14 kPa in adjacent industrial facilities	50
Toxic concentrations in residential areas which would be seriously injurious to sensitive members of the community following a relatively short period of exposure	10
Toxic concentrations in residential areas which should cause irritation to eyes or throat, coughing or other acute physiological responses in sensitive members of the community	50

* pmpy = per million per year

To put these risk criteria into perspective, the NSW Department of Urban Affairs and Planning has published data of risk to people from various common activities. Table 2 gives a summary of this information. By comparison of the two tables, the risk criteria are comparable to the risks we are all exposed to and accept as part of life, eg. from domestic fires, electrocutions and storms.

Table 2 – Risks to Individuals in New South Wales

ACTIVITY / TYPE OF RISK	PUBLISHED RISK LEVEL pmpy*
Voluntary Risks (averaged over active participants)	
Smoking	5,000
Drinking alcohol	380
Travelling by car	145
Swimming	50
Playing rugby	30
Travelling by train	30
Travelling by aeroplane	10
Involuntary Risks (averaged over whole population)	
Cancer	1,800
Accidents at home	110
Struck by motor vehicle	35
Fires	10
Electrocution (non industrial)	3
Falling objects	3
Storms and floods	0.2
Lightning strikes	0.1

* pmpy = per million per year

2 PROJECT DESCRIPTION

The Syerston Nickel-Cobalt Project consists of the following main components:

- Mine site (including mining areas, nickel and cobalt extraction and refining plant and power generation and gas plants);
- Limestone quarry;
- Rail siding;
- Water pipeline and borefield;
- Natural gas pipeline; and
- Road upgrade.

2.1 Mine Site

Land use surrounding the mine site is largely agricultural and is dominated by sheep farming and cropping (generally wheat).

The mine site is located at Syerston near the village of Fifield, in the district of Parkes in the Central Western Region of New South Wales. Syerston falls within the Shire of Lachlan. Syerston is located 45 km north east of Condobolin. See Figure 1 for location details.

The mine site is accessible by road. It is 470 km by road from Sydney and 630 km by road from Newcastle. The nearest rail station is Trundle which is 30 km away by road. There are no ecologically sensitive areas (eg. National Parks, wetlands) in the immediate vicinity of the mine site.

The town of Fifield is located approximately 4 km south-east of the mine site. Locations of nearby residences from the processing plant are:

- “Kingsdale” 1.75 km east
- “Sunrise” 3.75 km south-west
- “Wanda Bye” 3.45 km south
- “Slapdown” 4.65 km east
- “Currajong Park” 5.1 km north

For the purpose of the assessment the mine site has been divided into the following components:

- Ore processing plant area,
- Ancillary plants and infrastructure, and
- Mining and mine waste disposal areas.

2.1.1 Process Plant

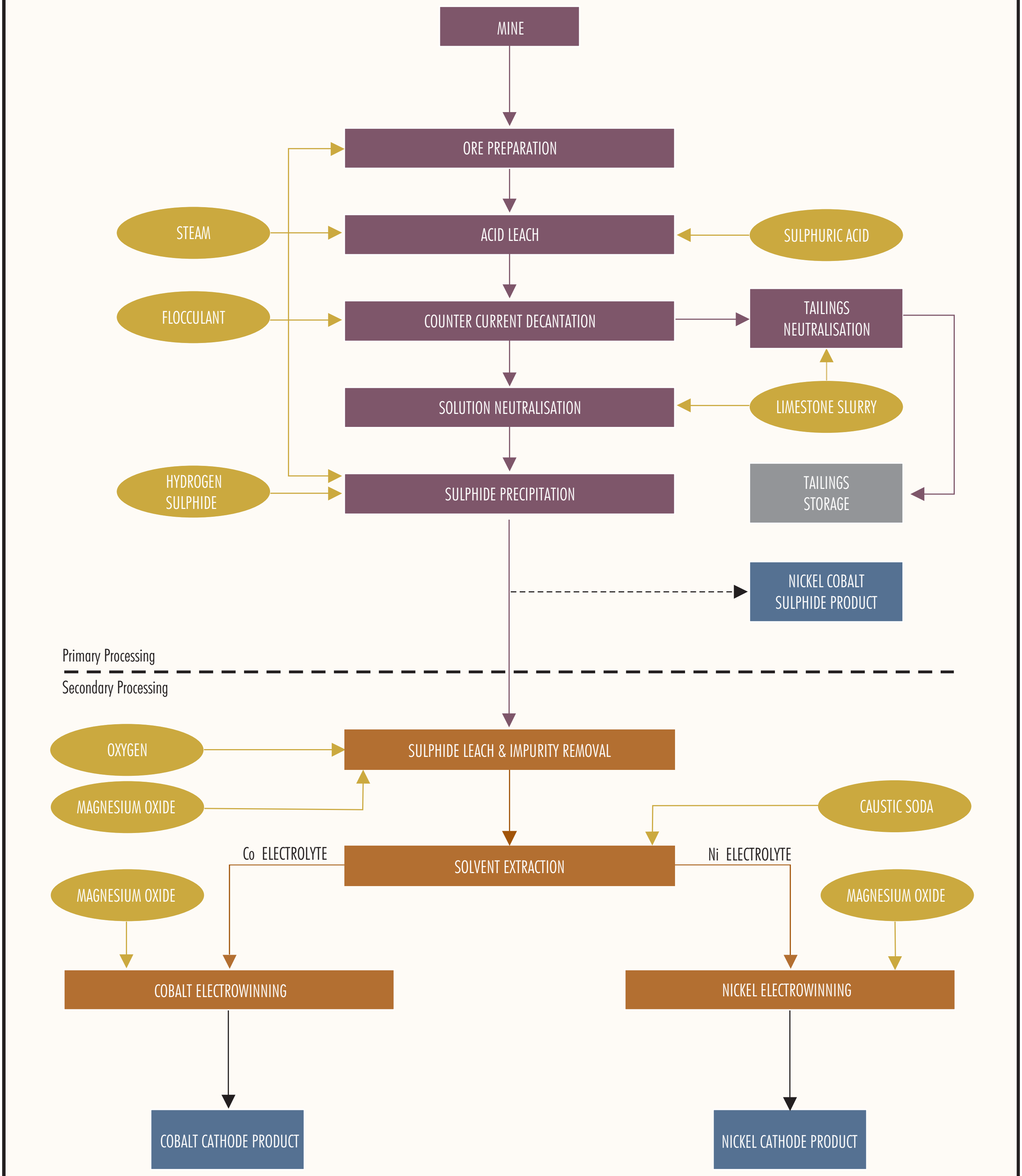
The primary aim of the processing plant is to produce metal products but intermediate products are saleable if the market dictates. The marketable products and rates of the proposed plant are:

- Nickel metal cathode, 20 000 tpa (tonnes per annum)
- Cobalt metal cathode, 5 000 tpa
- Mixed nickel cobalt sulphide powder, 42 000 tpa
- Cobalt hydroxide precipitate, 11 000 tpa

As described in Ref 3 and Ref 4, the proposed processing plant will consist of the following major components:

- Ore preparation facilities
- Limestone slurry preparation facilities
- High pressure acid leaching (HPAL)
- Counter current decantation (CCD) washing
- Tailings neutralisation
- Solution neutralisation
- Sulphide precipitation
- Sulphide releaching and impurity removal
- Nickel, cobalt and zinc solvent extraction, and
- Nickel and cobalt electrowinning

A block diagram of the overall process is shown in Figure 2. The layout of the site, including the above areas, is shown in Figure 3.



Source: After SNC-Lavalin (2000) & BRM (2000)

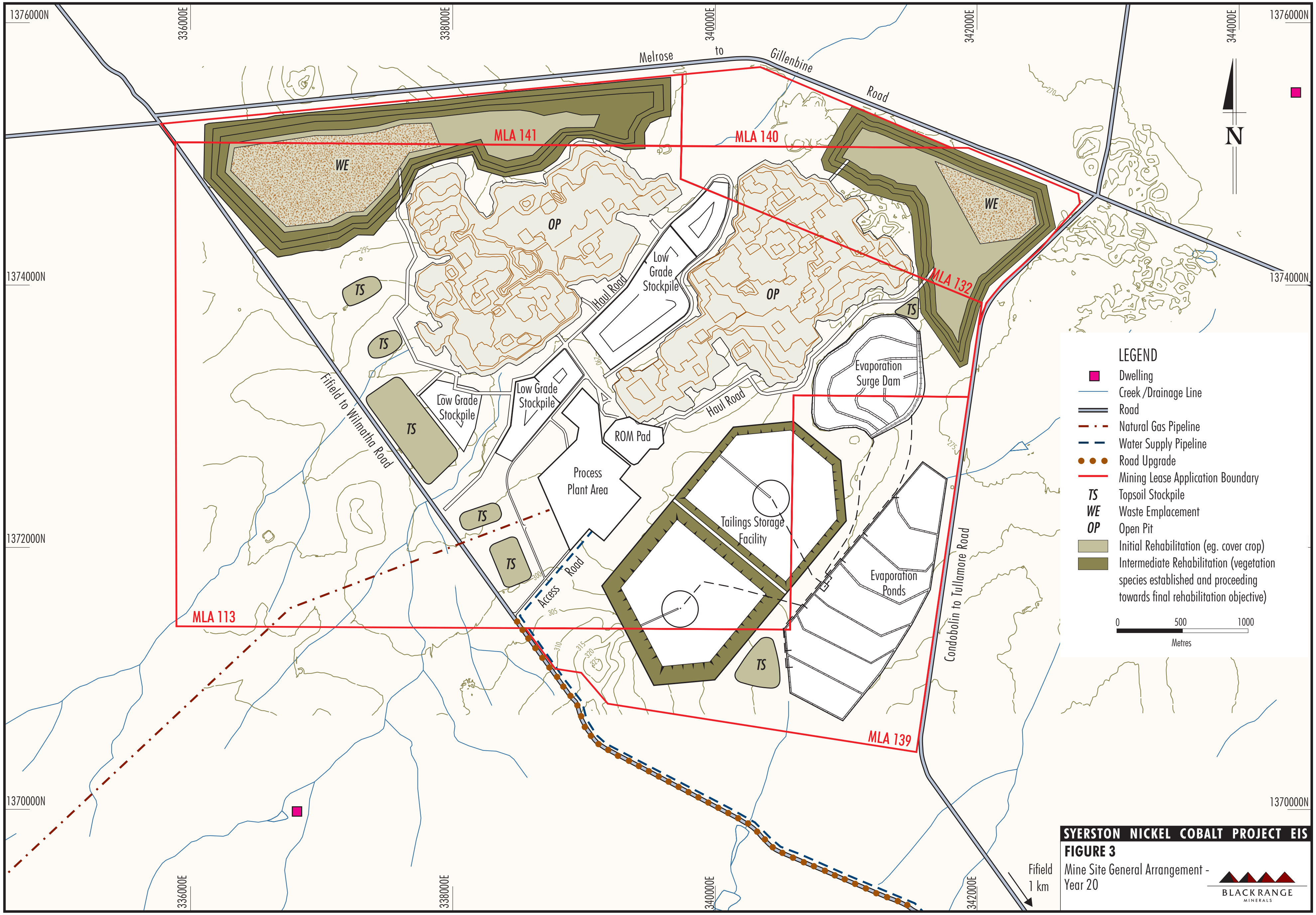
SYERSTON NICKEL COBALT PROJECT EIS

FIGURE 2

Ore Processing Block Diagram

ResourceStrategies

BLACK RANGE MINERALS



SYERSTON NICKEL COBALT PROJECT EIS

FIGURE 3

Mine Site General Arrangement - Year 20

BRM-98-01-Risk_003B

2.1.1.1 Processing Plant Design Philosophy

The principles applying to the design of the plant are as follows:

- The circuit will be as simple as possible (consistent with the requirements of the process)

- The plant will be automated where practical and appropriate and be easily operated and controlled with minimal requirement for personnel with specialised skills

- The plant will be easily maintained by mobile equipment, generally in preference to, but not necessarily to the total exclusion of, permanent cranage

- The appropriate surge capacity will be provided between plant sections to maintain a high level of plant utilisation

- Installed spare equipment will be provided where bypassing of a unit operation is either inappropriate or not possible

- No specific provision will be made for significant plant expansion.

2.1.1.2 Process Control Philosophy

The overall control philosophy adopted for the study is the provision of a reliable and effective control system which will be a critical element in achieving the design performance of the plant. Features of the control system are as follows:

- The plant's unit operations will be arranged in logical groups or modules for ease of control; modules operate under operator-initiated startup and shutdown sequences

- Process control loops will be provided for regulation of the important process variables

- Plant sequencing and control functions will be implemented using the simplest logic possible, commensurate with safe, rapid and effective startup, shutdown, trip and process control routines

- Dependence on field devices will be minimised to ensure that failure of non-critical devices has minimal impact on plant availability

- The control system will be used for plant sequencing and process control, providing the necessary interlocking between drives, valves and modules and the control of process variables. It will also provide the means for monitoring plant and process status

- For most slurry pumping duties, two pumps will be provided for a given function, one of which will be nominated the duty unit and the other (by default) the spare; hot-change facilities will be provided to avoid operational interruptions

- Overall control of the plant will be exercised from a central control room.

2.1.1.3 Ore Preparation

Ore from the mining operation will be delivered to the ROM (run-of mine) stockpile at the plant. The ROM ore pad will have a surface area of 400 m by 200 m and will be constructed in two levels for truck tipping and loader reclaim. Two blending stockpile areas will be used on the ROM pad.

Front-end loaders will feed ores of varying grade and characteristics from the stockpile into the crushing circuit. Ore will pass through a bin to a mineral sizer and will then be conveyed to the slurrying mill where process water will be added.

The mill discharge screen aperture will be set to pass material of less than 1 mm to the mill discharge pump box from which the slurry is pumped to leach feed storage tanks. Material greater than 1 mm will be conveyed as reject to a stockpile. This will equate to less than 5% of mill feed in the case of goethite ore (the preferred, better quality ore). For siliceous goethite ore (ore that has quartzlike intrusions which are devoid of metal value), the reject rate will be between 20% and 40% of mill feed.

Note: There will be no explosives stored or used at the site. The ore will be removed from the ground by mechanical techniques.

2.1.1.4 Limestone Preparation

Limestone mined from local deposits by open cut mining methods will be trucked to the plant site for processing into a slurry. The limestone will be dumped onto the ROM limestone stockpile to be reclaimed by front end loader or direct tipped into the crusher hopper. The ROM limestone will be crushed through a conventional crushing and screening circuit and ground in a mill to achieve 80% passing 75 microns at 40% solids slurry.

Milling will include a mill and cyclone classification circuit. The product slurry will be pumped to two storage tanks of nominally 24 hours capacity, which will be agitated to prevent settling. Limestone slurry is then distributed to the leach solution, tailings and barren solution neutralisation circuits.

2.1.1.5 High Pressure Acid Leaching Circuit

The acid leaching circuit will consist of a single autoclave train. The autoclave will be 5.6 m in diameter and 36 m long, constructed of carbon steel and lined internally with titanium. The autoclave is divided into 6 compartments and equipped with 7 agitators. The acid leach circuit will extract 92-95% of the nickel and cobalt from the feed ore.

Slurry from the ore preparation facilities will be fed to the autoclave under high pressure by centrifugal and positive displacement pumps through three stages of pre-heaters. The pre-heaters will use steam produced by the flash vessels to heat the incoming slurry before being further heated to about 230^{o}C using high pressure steam generated from the acid plant. Feed slurry (35-45% solids by weight) will then enter the first compartment of the autoclave with sulphuric acid (98 wt%) dosed at 265 kg per tonne of dry ore.

The autoclave slurry will discharge to the three stages of flash vessels. Steam produced in the flash vessels will be used as a heat source in the feed pre-heaters. Slurry will be progressively “let down” to atmospheric pressure in these flash vessels. The slurry from the atmospheric flash vessel will then be pumped to the counter current decantation circuit.

2.1.1.6 Counter Current Decantation (CCD) Washing Circuit

The CCD washing circuit will be used to separate the soluble nickel and cobalt sulphate in solution from the autoclave discharge slurry solids produced in the acid leach circuit. This circuit will comprise nominally seven stages of re-pulping or “washing” of the slurry with a solution followed by thickening of the residue solids to remove the diluted solution containing the metal sulphates. A flocculant will be added to promote settling at each thickening stage.

The discharge slurry from the acid pressure leach train will be pumped to the first wash thickener where it will be re-pulped, diluted with the second wash thickener overflow and mixed with recycled gypsum from the solution neutralisation process. The overflow from the first wash thickener will be pumped to the solution neutralisation circuit. The thickened solids or underflow from the first wash thickener will be pumped to the second wash thickener to be repulped and diluted by the overflow solution from the third wash thickener.

The remaining CCD stages operate in a similar fashion.

In the final wash thickener, recycled barren solution from sulphide precipitation is added as wash solution. Underflow from the final wash thickener is pumped to the tailings neutralisation circuit.

2.1.1.7 Tailings Neutralisation Circuit

In the tailings neutralisation circuit, underflow from the CCD washing circuit will be combined with bleed solution and neutralised to pH 6-7 using limestone. The neutralised slurry will be pumped to the tailings dam.

2.1.1.8 Solution Neutralisation

The solution neutralisation circuit will reduce the excess acid concentration to a level that facilitates precipitation of the valuable metals as sulphides resulting in high overall nickel and cobalt recovery. Overflow from the CCD circuit will be partially neutralised using limestone slurry to form gypsum. This gypsum will be removed from the neutralised solution via thickening. The gypsum slurry from the thickener will be recycled to the CCD circuit and the clear, neutralised product solution will be pumped to the mixed sulphide precipitation circuit.

2.1.1.9 Mixed Sulphide Precipitation Circuit

The nickel/cobalt mixed sulphide will be recovered in the sulphide precipitation circuit as a filter cake from the neutralised solution.

Neutralised solution and recycled seed material from the sulphide precipitation thickener will be mixed in the sulphide precipitation feed tank. Slurry from the feed tank will be pumped into two sulphide precipitation autoclaves in parallel where hydrogen sulphide gas is injected to precipitate the nickel and cobalt (as sulphides). Excess hydrogen sulphide will be progressively let down in pressure and recycled to the solution neutralisation circuit upstream of the sulphide precipitation autoclaves. This circuit is vented to the plant flare system. Solution from the sulphide precipitation autoclave will be let down to the flash vessels.

The flash tank vapour will be recycled in order to scrub residual hydrogen sulphide; the depressurised slurry will be pumped to the sulphide thickener.

The thickener separates the barren solution from the mixed sulphides that will exit in the underflow. The underflow will be filtered to recover the nickel and cobalt sulphides as a mixed sulphide filter cake (either bagged for storage or repulped for grinding). The filtrate and thickener overflows are waste products referred to as barren solution of which a portion will be recycled to the CCD wash circuit and limestone grinding. The balance flows to the tailings neutralisation area.

The mixed sulphides will be used as the feed for the downstream nickel-cobalt refinery or can be sold as an intermediate product.

The sulphide grinding circuit consists of storage tanks, a fine grinding mill and a cyclone cluster. Sulphides are repulped using high quality or spent electrolyte from the electrowinning circuit. The repulped sulphides are pumped to a storage tank prior to grinding in a fine grinding mill and cyclone circuit. Cyclone overflow slurry product is stored in a surge tank and either pumped to the sulphide leach circuit or recycled as seed for sulphide precipitation.

2.1.1.10 Nickel-Cobalt Refinery

Mixed Sulphide Leaching

Leaching of the mixed sulphide is necessary to produce a high strength nickel/cobalt sulphate solution prior to cobalt and zinc solvent extraction and nickel and cobalt electrowinning.

The fine, ground mixed sulphide slurry will be pumped under pressure into an autoclave for leaching. The autoclave will be divided into 6 compartments and equipped with 6 agitators. Oxygen will be injected into a sulphide leach autoclave to react with the mixed sulphide to produce a nickel and cobalt sulphate solution.

The solution from the autoclave will be continuously discharged to a flash tank and the generated vapour will be recovered via coolers. The flash tank will drain to a sealed tank and slurry will be pumped to a series of tanks for neutralisation and precipitation of impurity metal ions prior to solvent extraction. These impurities either contaminate the final nickel and cobalt products or foul the solvent extraction circuit organic phase.

Impurity Removal

The impurity removal stage will remove metal ions such as iron, zinc and copper that affect the final product quality.

Partial neutralisation, using magnesia, will result in the formation of precipitates of iron and other compounds. Hydrogen sulphide can also be added at this stage to improve precipitation of copper and zinc. Precipitation of iron is facilitated by air blowing the solution to convert ferrous ions to ferric ions. The partially neutralised slurry will be thickened and the underflow pulp will be filtered. Overflow is also filtered to remove fine suspended solids. The filter cakes that originated from the underflow and overflow streams are recycled to ore preparation and leaching.

Following neutralisation and iron removal the pregnant leach liquor will be pumped to the cobalt solvent extraction area.

Cobalt Solvent Extraction (SX) and Recovery Circuit

The SX circuit removes cobalt and zinc from the nickel/cobalt sulphate solution produced from the impurity removal stage (in the form of a cobalt and zinc sulphate solution) leaving a solution of high purity nickel sulphate raffinate.

Zinc is extracted from the cobalt/zinc sulphate solution in the zinc SX circuit using an organic solvent which will be subsequently stripped to provide a solution of zinc sulphate which will be disposed of to tailings. Cobalt metal will be produced by sending the resulting strong cobalt sulphate solution to the cobalt electrowinning area.

Cobalt Production

The cobalt sulphate solution, which has undergone zinc removal, is then neutralised using magnesia. In this neutralisation process, cobalt is precipitated as a hydroxide. This hydroxide precipitate is then filtered and collected as a cake. The solution goes to a brine evaporator where a magnesium/sodium sulphate salt is produced. The clean solution is recycled to the sulphide grinding circuit and the salt is disposed of in the tailings dam.

The filter cake is then redissolved in acidic anolyte (spent electrolyte) solution from the cobalt electrowinning cells. The resulting solution is clarified by filtration in preparation for the final step prior to electrowinning, which is lead removal. The solution is neutralised and lead is removed by selective precipitation as a hydroxide; the neutralising agent in this case is barium hydroxide. The precipitate comprising lead hydroxide and barium sulphate is filtered. The filter cake is disposed of via tailings neutralisation or sold for further refining.

The purified cobalt solution is then heated by heat exchange with warm anolyte and steam. The warm cobalt rich solution is then fed to the electrowinning cells.

The cobalt is plated onto pre-prepared cathode plates. These blank cathode plates are plates that have been recycled from the cobalt cathode stripping station. At the stripping station the cobalt which has plated on to the plates is stripped off leaving the blank cathode plates.

A small portion of the stripped plates may have areas where the cobalt could not be stripped off mechanically and, to recover the cobalt (and prepare the blank), this cobalt is dissolved away using nitric acid. Nitric acid dissolution of cobalt gives rise to nitric oxide gas, which is aspirated from the nitric acid wash tank by a fan and is dispersed to the atmosphere via the Nitric Stack. This operation will be a batch operation occurring over one to two days each week during which time the nitric oxide vent rate is approximately 7 g/s.

The cleaned blank cathode plates are dipped in a solution of gelatine and then air dried. A film of gelatine a few microns thick dries on to the plate. The gelatine acts as a releasing agent and facilitates stripping.

The sheets of cobalt stripped from the cathodes are chopped up in a guillotine into pieces, which are fed into the cobalt crusher. The crushed cobalt is screened with the coarse fraction sent to the vacuum degassing furnace. The vacuum degassing furnace is a heated, evacuated chamber, which allows hydrogen, oxygen and nitrogen gases absorbed in the cobalt to desorb.

The crushed, degassed cobalt product is then fed to the burnishing drum where the cobalt chips are tumbled to improve their appearance. The cobalt product is then packaged into 250 kg drums.

Nickel Production

Nickel-rich solution from the cobalt/nickel solvent extraction area is neutralised using magnesia. During this neutralisation, nickel is precipitated as a hydroxide. This hydroxide is recovered by filtration. The solution goes to a brine evaporator where a magnesium/sodium sulphate salt is produced. The clean solution is recycled to the sulphide grinding circuit and the salt is disposed of in the tailings dam.

The nickel hydroxide filter cake is redissolved using nickel anolyte from the electrowinning cells. The solution is then filtered and neutralised with barium hydroxide. Lead hydroxide is selectively precipitated and filtered off leaving an essentially pure solution of nickel sulphate, which is then fed to the nickel electrowinning section. The lead hydroxide filter cake is transferred to the tailings neutralisation area or sold for further refining.

Nickel is plated on to starter sheet cathodes, which are progressively loaded by nickel metal in the electroplating process.

These starter sheet cathodes are thin sheets of nickel, which have been formed on titanium cathodes in a separate electroplating process. The starter sheets are peeled from the titanium cathodes and then have nickel loops added to make them suitable for use as electrowinning cathodes.

Lead anodes are used in both the starter sheet cells and the nickel production cells. These anodes are surrounded by an anode frame which supports an anode bag. Electrolyte flows through the anode bag from the cathode to the anode. Anolyte is removed, along with the gases generated during electrowinning, from the anode bags into the anolyte extraction header running the length of the cell along to one side, by the nickel anolyte vacuum pump. The combined aqueous/gas phase is then fed to a gas separator where the anolyte and gases recovered from the anolyte bags are separated. The solution is recovered and returned to the electrowinning anolyte recirculation tank.

The gas phase will be collected and scrubbed before venting to the atmosphere. The vent gas consists of water vapour (95.5%), oxygen (4.4%) and hydrogen (0.1%).

Loaded nickel cathodes are removed from the electrowinning baths and then washed. Subsequently the nickel cathode is bundled on pallets for sale or guillotined and chopped onto pieces. The pieces are then packed into 250 kg drums for export.

2.1.1.11 Process Plant and Site Run-off

The plant site drainage system will be designed to catch all stormwater on the plant site outside the process areas. The system will comprise a network of open earthen drains and culverts which will gravitate to the settlement pond. The settlement pond will capture the sediment. The water will be pumped from the settlement pond to the process pond. The drains will be designed for a 1 in 100 year event and the settlement pond will be designed to contain the rainfall run-off for the 1 in 10 year, 24 hour storm event. The EPA are expected to review event design criteria prior to implementation.

Rain falling on the process areas will be contained within bunded areas (which include pumps and sumps).

2.1.1.12 Process Spillages

The majority of process areas will be provided with bunded areas to contain process spills. These areas will be concreted and sealed where required. Collection sumps will be provided within the bunds with pumps, either fixed or mobile, to pump spills back to the process.

2.1.1.13 Proposed Fire Protection System

The entire process plant area will be serviced by double head firewater hydrants in accordance with AS 2419 – Fire Hydrant Installations.

In addition, the solvent extraction area will be serviced by a foam deluge system. The solvent extraction (SX) area processes an organic solution that consists predominantly of a diluent called Shellsol which is a type of kerosene which has a flash point of 78°C. The SX area consists of tanks, pulsed columns, filters, mixer/settler tanks and electrically powered centrifugal pumps. In the event of a spill, a concrete bund wall that surrounds the area contains all liquid. Within this bunded area there will be partition bund walls to separate the different stages of the SX process.

The foam deluge system for the SX area is to consist of hydrant mounted foam monitors, fixed low-level foam-water discharge outlets and heat activated foam-water deluge sprinklers. The entire SX area will be serviced by infrared flame detectors which automatically activate the low-level foam-water discharge outlets in the event of a fire. The flame detectors shall be failsafe including wiring and associated equipment. A bladder tank proportioning system will be used for foam addition.

The system will include fire protection equipment for the mine site's diesel fuel storage tanks to meet the relevant Australian Standards for storage of flammable liquids (eg AS 1940).

The firewater pump set shall be comprised of an electrically powered 100% duty pump, a diesel powered 100% standby pump and an electrically powered pressure maintaining 'jockey' pump. The jockey pump will be used to maintain system pressure in the ring main. This will be necessary because of pressure losses caused by normal system losses. The jockey pump prevents premature starting of the main fire service pumps. Large pressure drops in the ring main caused by a hydrant being used will cause the electric fire water pump to start automatically. In the event of a power failure or the electric powered pump fails to start the diesel-powered pump will start automatically.

A fire suppression system is to be installed in the plant's central control room and in each of the plant's electrical substations. Each fire suppression system is to consist of a gas storage facility, dual risk detection system, warning and evacuation alarms and distribution piping and fittings.

The system will also include hand held, manually operated fire extinguishers throughout the processing plant, administration buildings, workshop, metallurgical lab and MCC rooms for first aid fire fighting.

The fire protection system will:

- Have 100% availability
- Be hardwired back to a Fire Alarm Panel located in the plant's central control room to enable remote monitoring of system alarms and system status. All instruments shall be fail-safe
- Hardwired to visual and audible alarms located throughout the processing plant.

2.1.2 Ancillary Plants and Infrastructure

For the purpose of the assessment the mine site's infrastructure and service facilities have been included within the general ancillary plants and infrastructure description. They comprise:

- Process water supply system;
- An on-site power station, fuelled by natural gas, to produce electric power and steam
- Oxygen, nitrogen, hydrogen and hydrogen sulphide gas production plants
- A sulphuric acid plant
- Fuel farm
- Reagents handling and storage areas
- Hydrogen sulphide flare
- Buildings, including a workshop/warehouse, offices, amenities, gatehouse and laboratory
- Water treatment plant
- A communications system

2.1.2.1 Process Water Supply System

Raw water will be supplied from a series of bores to a main supply pipeline feeding the processing plant. Raw water from the 65 km main trunk pipeline will be fed into a raw water storage tank of 2 000 m^3 capacity. The water from the raw water tank will be either pumped to the water treatment plant or will overflow into the raw water dam. The raw water dam will hold four days supply of water, ie 30 000 m^3. The earthen bunded dam will be dug into natural ground level to a depth of approximately 4 m. The bund walls are stabilised with 3% cement surface layer, 50 mm thick. Containment of water will be achieved by a 1 mm impervious HDPE liner laid on a 50 mm sand layer, over a compacted surface. Water will be drawn via piping buried in the dam walls and originating in concrete sumps set in the dam floor.

The dam supplies the following users:

- Firewater ring main
- Cooling water
- Process water
- Potable water plant/storage, and
- Demineralised plant/storage

An off-take from the pipeline ahead of the raw water tank will feed water to the potable water supply tank. The potable water will be dosed with chlorine.

Raw water will be filtered and will then be fed through polishing filters.

Filtrate will be then dosed with anti-scalant before being further filtered in reverse osmosis (RO) units to remove ionic species and silica. Retentate from the reverse osmosis units (ie the stream more concentrated with the impurities) will be fed to the process water system which is used for ore slurry preparation. Other streams to be used in the ore preparation area include the water and steam blowdowns.

Permeate from the reverse osmosis units (ie the stream with less impurities) will then pass through a series of ion exchange (IX) units to produce demineralised water suitable for use within the boilers.

There will be several exchange units which will allow continuous production of demineralised water. Loaded beds will be regenerated with sulphuric acid and caustic soda. Regeneration and rinse waters will be directed to ore preparation.

There will be one evaporative cooling water supply system (31 MW power plant cooling tower) on the site.

2.1.2.2 Steam and Power Generation

Electricity will be generated by two 20 MW gas turbines fitted with a single Heat Recovery and Steam Generation (HRSG) unit and a 10 MW steam turbine.

The power generation and distribution system will provide electricity for the plant power requirements for both normal and emergency operations. Maximum power demand requirements for the project are anticipated to be in the order of approximately 34 MW.

The gas turbine will also have low emissions of oxides of nitrogen and exhaust emissions are expected to be less than 0.7 grams of NO_2 (or NO_2 equivalent) per cubic metre of turbine exit gas. Sulphur dioxide emissions from the gas turbines are expected to be low as the total sulphur in the Moomba-Sydney gas pipeline averages 6 mg per standard cubic metre. This equates to an emission rate of 0.03 g SO_2 per second.

Emergency backup power supply is proposed to be provided by diesel fuelled generators with a capacity of approximately 5 MW. Fuel for the diesel generators will be sourced from the 50 000 L plant diesel tank and stored locally in an above ground storage tank (nominal capacity of 5 000 L) in accordance with the relevant Australian Standards for storage of flammable liquids (eg AS 1940). This is sufficient for one day's operation.

Steam will be raised by three separate units:

- The power plant gas turbines HRSG
- The sulphuric acid plant waste heat boilers, and

- An auxiliary boiler.

There will be three levels of steam for use throughout the processing areas: 6 MPa superheated steam, 6 MPa saturated steam and 600 kPag saturated steam.

2.1.2.3 Industrial Gas Plants

Industrial gases are required for certain chemical reactions in the processing operations. The anticipated gas requirements for the project are:

↓ Oxygen 120 tpd (tonnes per day)

↓ Hydrogen 3.85 tpd

↓ Nitrogen 15 tpd, and

↓ Hydrogen sulphide 62 tpd

The industrial gas facility will utilise air, natural gas and sulphur as feedstock as required.

There are two options available for air separation into oxygen or nitrogen. The first is cryogenically in a conventional air separation unit (ASU). The second is at ambient temperatures in a pressure swing absorption (PSA) unit. As the cryogenic process involves slightly more hazardous operations, it is the option reviewed in this study. The main hazards associated with oxygen streams are, of course, common to both processes.

The cryogenic process typically involves air compression, drying, cooling and cryogenic distillation in a double column arrangement (the condenser for the bottom column is the reboiler for the top column). Both gas and liquid products can be supplied from the ASU. The oxygen will be used in the sulphide leaching process. The nitrogen will be used for plant purge uses.

Hydrogen will be produced on-site by the reforming reaction between natural gas and steam. Natural gas is mixed with steam and superheated in a feed preheat system and then passed through the catalyst filled tubes in the reforming furnace. In the presence of the nickel based catalyst, the mixture reacts to produce hydrogen and carbon oxides. Heat for the endothermic reforming reaction is provided by external firing in the reformer.

The gas stream leaving the reformer is cooled by generating steam which is used for the reforming reaction and boiler feed water preheating. From the steam generator, the gas passes to the shift converter, where carbon monoxide and water vapour react to form hydrogen and carbon dioxide.

The shift converter effluent gas is cooled and the hot condensate separated. The process gas is then cooled in an air cooler and a water trim cooler before being sent to the pressure swing absorption (PSA) system.

In the PSA section, carbon oxides and residual methane are removed by beds of solid absorbent. The absorbent is regenerated by depressurisation and purging. Purge gas from the PSA section is used as fuel in the reformer. The product hydrogen gas from the PSA section is used to make hydrogen sulphide gas.

Hydrogen sulphide gas will be produced by passing hydrogen through molten sulphur. Liquid sulphur from the acid plant melting pit is pumped to the hydrogen sulphide plant area and into the top of a vertical packed column reactor operating at 1 500 kPa. The liquid sulphur is recirculated around the vessel. Hydrogen is injected at the bottom of the vessel where the two react exothermically. Hot hydrogen sulphide is withdrawn from the top, cooled and delivered to the sulphide precipitation circuit. During normal operations, there are no emissions from the hydrogen sulphide plant.

Storage of all industrial gases will be kept to a minimum but will be sufficient to allow for surge and continuity of operations; typically 1 day of storage.

In addition to the above plants, both instrument and plant air will be supplied to various users throughout the site.

2.1.2.4 Sulphur Handling and Sulphuric Acid Plant

Sulphur will be received at the port of Newcastle in shipments of around 25 000 te (tonnes). The ships product reclaimer will transfer the sulphur to existing receival facilities. The sulphur will then be transferred to trucks which will take the sulphur to a new sulphur stockpile near the railhead. This stockpile in Newcastle will be 30 000 te. This facility is subject to a separate EIS study.

Sulphur reclaimed from this stockpile will be transferred to specially constructed containers. The containers (24 te capacity) will be railed to the siding where they will be unloaded by a container forklift on a hardstand surface.

Trucks will deliver the contained sulphur to the mine site for acid production after collection from the rail siding. The sulphur will be dumped into a hopper, which may direct material via conveyors to either a sulphur melting pit or a stockpile. Water dosed with dust suppressant chemical will be sprayed at the receival hopper, hopper transfer points and the reclaim hopper to minimise dust generation and hence the possibility of an explosion. The discharge head chute in particular will utilise fog nozzles for this purpose. Surface water run off in the immediate vicinity of the stockpile will be collected and transferred to the tailings neutralisation circuit.

Sulphuric acid is produced on-site using a conventional sulphur-based double contact acid plant.

Atmospheric air is drawn by the air blower and passed to a drying tower, where contained moisture in the air is absorbed by sulphuric acid flowing in a countercurrent direction to the air, producing dry air. Water removed from the air dilutes the circulating acid and generates heat (that is removed in the drying tower circuit). The dry air passes through a demister to remove entrained acid mist and flows to the sulphur furnace for the combustion of the molten sulphur.

Molten sulphur at a temperature of $130^{o}C$ to $135^{o}C$ is sprayed into the sulphur furnace through a sulphur gun. The sulphur oxidises to form sulphur dioxide.

The hot SO_2 enriched process gas concentration is approximately 10.5 volume percent SO_2. This process gas is forced through a boiler and superheater to produce superheated steam. The steam is exported to the plant battery limits for use in other areas. A hot gas bypass is provided across the boiler to optimise gas temperature for the first catalyst layer of the converter.

The SO_2 rich process gas passes through a number of layers in the converter (with intermediate heat exchange) where the sulphur dioxide is converted to sulphur trioxide in the presence of vanadium pentoxide catalyst. The sulphur trioxide rich gas stream flows from the converter to the first economiser, where it is cooled prior to entering the first absorption tower.

The sulphur trioxide is absorbed in strong sulphuric acid (98 wt%) in the first absorption tower. After the sulphur trioxide is removed, the gas stream flows through a two stage demister to remove any entrained acid mist.

The gas stream then flows to a final conversion layer of catalyst and through a second economiser where the gas is cooled. The sulphur trioxide is removed from this stream in a second absorption tower.

The dilute acid formed during absorption of atmospheric moisture in the drying tower and the acid concentrate formed in the first absorption tower are mixed together in a common pump tank. Dilution water is added to this tank to maintain acid strength at 98.5 wt%. The heat of dilution evolved in the drying tower and exothermic heats of reaction in the first and second absorption towers, together with the sensible heat differentials of the respective gas streams is removed in the respective acid coolers by cooling water. Product acid is removed through the product cooler and sent to the storage tank from the second stage absorption tower system. This reduces the loss of dissolved sulphur trioxide in the acid product.

Acid production will be approximately 0.6 Mtpa with a design base for consumption of up to 265 kg of sulphuric acid per tonne of ore.

A 10 000 tonne on site storage tank is provided with lined earthen bunding. Pumps are placed in an acid resistant concrete bund equipped with sumps.

During periods of high acid demand sulphuric acid will be trucked in. A road tanker unloading station is provided for this.

The sulphuric acid produced will be used in the process as follows:

- Acid leaching of the ore, and
- Solvent extraction

2.1.2.5 Fuel Farm

The fuel farm will consist of one 50 000 L double walled diesel tank. Diesel will be available via either high or low speed bowsers. A storage tank for solvent extraction diluent (similar to diesel) will be located in an earthen bund local to the solvent extraction plant. Diluent will be pumped to the solvent extraction area directly. An additional two bunded 50 000 L diesel tanks would be located at the mining contractor area. Surface run-off from bunded areas will be collected in a corrugated plate interceptor with oil available for collection and recycling. Water will be directed to the tailings thickener area.

Diesel will also be stored in the emergency diesel generator tank (5 000 L) and in the firewater pump tank (1 000 L).

Lubricating oils and greases will also be stored on-site. Specialised lubricants will be kept in barrels with hand pumping facilities. All oil storage systems will incorporate small circulating pumps to minimise the effects of bacterial attack.

2.1.2.6 Caustic Soda Storage

Caustic soda (sodium hydroxide) is used throughout the process as a neutralisation agent. It will be delivered to site in road tankers and stored in a 200 m^3 tank. The concentration will be 50 wt%.

2.1.2.7 Hydrogen Sulphide Flare

There will be a single flare stack at a safe location from the process plant. The flare system will flare hydrogen sulphide from two sources:

- The sulphide precipitation circuit, and
- The hydrogen sulphide plant.

The gas streams from these two sources will have their own collection headers and flare KO (knock-out) drums. The streams will be piped separately to the flare tip. The flare stack is proposed to be 80 m high. A 60 m sterile zone is proposed around the base of the flare. Natural gas will be used as an assist gas to ensure complete combustion of H_2S in the vent gases to SO_2.

The flare will be smokeless under all operating conditions.

2.1.2.8 Site Buildings

In addition to the processing plant, various buildings would be constructed which include a construction phase accommodation camp, general administration offices, workshop/warehouse, amenities, gatehouse and laboratory. Except for the accommodation camp all additional buildings would be constructed in the general process plant area.

The gatehouse provides the security check-point for all vehicles and personnel entering the mine site. This area also includes security boom gates. The mine site will be fenced with signage around the perimeter.

2.1.2.9 Water Treatment Plant

A water treatment plant would be located in the general process plant area. It would consist of a filtration plant, reverse osmosis treatment plant, demineralised water treatment plant and demineralised water storage tank and pumping station.

2.1.2.10 Communications System

A mine site communication system would be established including a site telephone system and radio communications with select channels for mine fleet and processing plant area. Standard radio operator safety protocols would be implemented within the communication system. A telemetry system would be implemented for the control of water supply from the borefield and water flow through the water pipeline.

2.1.3 Mining and Processing Waste Disposal Areas

The development of the Syerston deposit would involve conventional open pit mining methods at depths of generally 50 m below the surface. The mine plan includes development of multiple open pits in the initial years of mine life which would be expanded to create a single open pit toward the end of the mine life.

The mining method would comprise free digging by excavator. Blasting is not expected to be used during mining. Ore and waste would be loaded directly to haul trucks for transfer to either the ROM pad, low grade stockpiles or the waste emplacements.

Mine waste would include waste rock (ie excavated material not required for mineral processing) and processing wastes including tailings. Mine waste rock would be loaded directly to haul trucks in the open pits and transferred to waste emplacements. Mine tailings would be pumped via pipeline in slurry form to the tailings storage facilities. Waste water or supernatant in the tailings facilities would be pumped to the evaporation ponds and onto the surge dam.

2.1.3.1 Tailings Disposal

Tailings discharge from the processing operations will consist of neutralised leach residue and gypsum slurry. The neutralised leach residue consists primarily of fine haematite and silica. Tailings thickener overflow and tailings dam decant water may be recycled to the limestone slurry areas and the ore preparation area for reuse.

Additional streams which will be directed to the tailings neutralisation area are:

- Flare KO drum liquids
- Sulphur stockpile sump
- Sulphuric acid plant sumps

- Regeneration and rinse water from the demin plant

These streams are neutralised and the heavy metals are precipitated as hydroxides.

2.1.3.2 Tailings Dams Residue (Residue Slurry)

The high pressure acid leach residue and gypsum slurry remaining after the CCD washing process, together with the bleed waste solution, will have a residual sulphuric acid level of about 1 g/L which will be neutralised to a pH of between 6 and 7 through the addition of limestone. The slurry at about 45% solids, will be pumped to the tailings dams for long-term storage at a rate of approximately 330 te per hour of dry solids.

The tailings dams will be designed to minimise seepage and minimise the disturbed area. The supernatant and rain volumes will be decanted by gravity to the evaporation pond to minimise the driving force for seepage. Rotation of the slurry discharge will be sufficient to maximise the final in situ density. Recovery of the decant from the tailings dam back to the process will be maximised.

These dams will be constructed in conventional sub-aerial fashion as per existing mining practice using compacted local materials to establish a base and starter walls.

2.1.3.3 Evaporation Ponds

The evaporation ponds will cover a total area of approximately 180 ha. The amount of solution discharged as waste will be determined by the overall water balance and impurity levels in the process stream, principally magnesium, calcium and chlorides (ie the process cannot withstand high impurity levels). The evaporation ponds are expected to receive approximately 400 m^3/hour of water from the tailings dams.

2.1.3.4 Oil Contaminated Liquid Wastes

Washdown areas for vehicles, mobile equipment and any other areas that are identified as potential sources of oil contaminated run-off will be designed to contain run-off. They will be designed as bunded areas which flow to one or more collection sumps. Accumulated rainfall drained from the bunded area will pass a coalescing plate separator to retain any oil or diesel contamination. The separated oil will be collected and sold to oil recyclers and the effluent directed to the stormwater system.

2.1.3.5 Solvent Extraction Crud Disposal

In the course of organic solvent and aqueous phase contacting and separating, an oily film of crud forms. Crud is an emulsion made up of grit, colloidal silica, denatured solvent and extractant. Crud will be treated by agitating with sulphuric acid and then passing to a settling cone. Recovered organic will be decanted off whilst the acidified residue will be returned to the counter current decantation area.

2.1.3.6 Sulphur Waste

Approximately one tonne per day of sulphur waste (60% sulphur, 40% diatomaceous earth, ash and carbon) will be generated in the sulphur handling area. This will be disposed via the tailings area.

2.2 Limestone Quarry

The proposed limestone quarry is located approximately 20km south-east of the mine site along Route 64 (see Figure 1). The proposed open pit area would be located approximately 350 m from public road Route 64. There are no ecologically sensitive areas (eg. National Parks, wetlands) in the immediate vicinity of the quarry.

Locations of the closest residences to the quarry are:

- Quade's property 1 km west
- Page's property 2 km north-east

Land use surrounding the limestone quarry is largely agricultural and is dominated by sheep farming and cropping (generally wheat).

Limestone from the proposed quarry would be used to neutralise acidic solutions from the proposed high pressure acid leaching facility on the mine site.

Activities at the limestone quarry would include mining, primary crushing and loading of product to haul trucks for transport to the mine site.

Limestone would be mined by drill and blast methods. During initial establishment of the quarry, it is expected that blast volumes in the order of 8 000 BCM's (bank cubic metres) per round would be achieved. As the mine increases in size, a single blast of 17 000 BCM's (up to a maximum 30 000 BCM's) each month would be sufficient to meet the Project's limestone requirements. Appropriate safety measures would be implemented during blasting (eg traffic controls on Route 64) and storage of explosive would be in accordance with the relevant Australian Standard.

A front end loader would load blasted material into haul trucks for transfer to the crushing facility, ROM high grade stockpile or low grade and waste storage area. Limestone mined at the quarry would be crushed on-site prior to trucking to the mine site for processing into a slurry. Mine site processing demand for limestone would be approximately 0.6 Mtpa which translates to a transport requirement of approximately 25 trucks per day from the quarry to the mine site. Accordingly, the road upgrade works (Section 2.5) would include appropriate intersection controls at the quarry in accordance with RTA and local council requirements.

2.3 Rail Siding

The proposed rail siding is located approximately 25 km south-east of the mine site and 5 km east of the limestone quarry. The proposed siding would be located at the eastern end of Route 64 on the eastern side of the Tottenham to Bogan Gate Railway. There are no ecologically sensitive areas (eg. National Parks, wetlands) in the immediate vicinity of the rail siding.

The closest residences to the siding are:

- “Glen Rock” 0.7 km south-west
- “Spring Park” 1.5 km north
- “Ballanrae” 1.5 km east.

Land use surrounding the proposed rail siding area is largely agricultural and is dominated by sheep farming and cropping (generally wheat).

The siding will serve as a loading and unloading point for the consumables transported by rail and as the export point for the nickel and cobalt product. The rail siding will be used primarily for the receival of sulphur. Activities at the siding would include train loading and unloading (by forklift), container stacking and truck loading and unloading. The siding would consist of a hard-stand container loading and stacking area, administration office and access road. The siding perimeter would be fenced. The access road would cross the rail line at an existing level crossing which would be upgraded in accordance with State Rail Authority requirements. Trucks would run from the siding to the mine site on a campaign basis when trains arrive. Appropriate safety controls in accordance with local council requirements would be implemented at the Route 64 – Bogan Gate Tullamore Road intersection and the siding access road and Bogan Gate Tullamore Road intersection.

2.4 Pipelines

Two pipelines, gas and water, are proposed to run to the mine site.

There is no local water suitable for supply to the mine processing plant and limestone quarry. Water would be piped to these sites via a buried (for the most part) pipeline supplied by borefields approximately 65 km south of the mine site near the North Condobolin Road. The borefield and start of the water pipeline are located approximately 1 km north of the Lachlan River. The majority of this pipeline would run within existing road reserves.

Natural gas would be used on site for power and steam generation and the production of hydrogen. Natural gas would be supplied to the site from a lateral of the Moomba to Sydney gas pipeline approximately 75 km south-south-west of the mine site. The pipeline would be approximately 90 km long and buried. The majority of the line would run within existing road reserves and would cross the Lachlan River near Condobolin.

The proposed water and gas pipe runs are also shown in Figure 1.

2.5 Transport

The various aspects of transport associated with the Project are:

- Rail transportation of bulk materials to, and from, the proposed rail siding using containers
- Road transport of limestone from the limestone quarry to the mine site

- Road transport of bulk materials, chemicals, reagents and goods to the mine site
- On-site transport and storage requirements
- Export of product from site

The rail system will be used primarily for the receival of sulphur and other reagents and supplies.

The bulk chemicals likely to be transported to the mine site by road tankers are Shellsol (the solvent extraction diluent), diesel, caustic soda (or rail), liquid nitrogen and oxygen (for startup), magnesium oxide, hydrated lime, sulphuric acid (for startup) and flocculant. Waste oil from the effluent separator is to be transported from the mine site by road tanker. The majority of the packaged chemicals (eg acids, bases and reagents in bulkiboxes, and, chemicals and catalysts supplied in drums, bulk bags or cylinders) are to be transported by road.

The mine site is accessible by the existing local road network. Two adjacent roads (Route 64 and the road from Fifield to the mine site) would require upgrading, and some re-alignment, with a tarmac in order to ensure adequate facilities for all necessary transport to and from the site. Road upgrade works would be in accordance with local council requirements and would consider the volume and type of traffic proposed for the road and appropriate safety considerations. Nickel and cobalt product would be exported from the site in containers via road to the rail siding and via rail transport to a suitable port (eg. Port Botany or Newcastle).

The sulphur transport will be a 210 000 tonne per annum operation involving bulk transport by ship from Vancouver to Newcastle and then by rail to the site.

An annual tonnage of 560 000 tonnes of limestone would be transported by road to the mine site from the limestone quarry.

3 HAZARD IDENTIFICATION

3.1 Materials Processed or Stored On-site

The identified materials processed or stored on site are listed in Attachment 1. Those materials that may be involved in a significant hazardous incident (primarily with off-site effects) have been listed below in Table 3, along with the type of incident each material may be involved in. An "X" indicates the relevant Project component as well as the material could be involved with the identified hazardous incident. Some relevant comments regarding the hazardous nature of the materials follow the table.

Table 3 - Significant Hazardous Materials

Plant and Material	Project Component				Type of Incident		
	Mine Site	Lime-stone Quarry	Rail Siding	Other	Fire	Explosion	Significant Toxic Effects
Sulphur Handling and Sulphuric Acid Plant							
Sulphur	X		X		X	X (dust)	-
Sulphuric Acid (>98 wt%)	X				-	-	X
Sulphur Oxides	X				-	-	X
Hydrogen Sulphide Plant							
Hydrogen	X				X	X	-
Hydrogen Sulphide	X				X	X	X
Oxygen and Nitrogen Production							
Oxygen	X				X (1)	-	-
Water Treatment							
Chlorine	X	X			-	-	X
Fuel Storage							
Diesel	X	X	X		X	-	-
Ore Processing Plant							
Solvent Extraction Diluent	X				X	-	-
Various Plants							
Natural Gas	X			X (2)	X	X	-
Explosives (Quarry)		X (3)			X	X	-

Notes:
1. Oxygen is not flammable but strongly promotes combustion.
2. Gas pipeline supply to the mining site.
3. Ammonium nitrate fuel oil is used for blasting at the limestone quarry.

3.2 Description of Significant Hazardous Materials

3.2.1 Sulphur

Sulphur is a flammable yellow powdery solid or liquid with a “rotten egg” odour. It is an eye, throat and skin irritant and although no exposure limits have been established, the OSHA (the US Occupational Safety and Health Administration) nuisance dust limit of 15 mg/m^3 and ACGIN (American Conference of Governmental Industrial Hygienists) nuisance dust limit TLV of 10 mg/m^3 for the eight hour time weighted average applies. Hazardous decomposition products include sulphur oxides (SOx), primarily sulphur oxide and sulphur dioxide.

Attention to dust control, sources of ignition and vapour formation must be made when considering storage and transport of sulphur. Adequate ventilation must be provided to maintain airborne concentrations below the recommended workplace standards.

The fire and explosion hazard of sulphur mainly results from sulphur dust or vapour. The autoignition temperature of sulphur is 235°C. Sulphur flames are nearly invisible during daylight hours. High temperatures and incompatible materials including oxidising agents, moisture, halogens and halogenated materials, metals, metal oxides, sodium nitrate, charcoal, hydrocarbons, potassium permanganate, ammonia and ammonium compounds and boron, should be avoided.

Generally, tanks, shipping containers and loading equipment must be electrically grounded. Totally enclosed motors, flame and spark arrestors on power equipment and non-sparking alloys will help minimise hazards. Sulphur should be stored and transported in accordance with the Australian Dangerous Goods Code.

For this Project, the sulphur would be transported in closed containers in prilled form and be stored in stockpiles. As such, minimal sulphur dust is expected.

3.2.2 Sulphuric Acid

Sulphuric acid is a colourless, oily viscous liquid with a strong pungent odour. It is non flammable but is highly corrosive, toxic and poisonous. The threshold value limit for sulphuric acid is 1 mg/m^3 and the STEL (Short Term Exposure Limit) is 3 mg/m^3. The odour threshold is 0.6-1 mg/m^3 although pure acid does not have good warning properties.

Sulphuric acid is a very powerful oxidiser that is incompatible with materials such as oxidising agents, organics, nitric acid, chlorates, carbides, metals (e.g. sodium, aluminium, potassium) and zinc oxide. Sulphuric acid may attack some forms of plastic, rubber and coatings.

In the presence of water, sulphuric acid is highly corrosive to most metals. It will react violently with water at concentrations greater than 90%. Flammable hydrogen gas may evolve upon contact with metals. Toxic sulphur oxides will evolve when the acid is heated to decomposition.

The potential evolution of toxic gases requires handling of sulphuric acid only in well ventilated areas. The store must be secure, dry and removed from the incompatible materials listed above. Small containers must be adequately labelled, protected from physical damage and sealed when not in use.

Although non flammable, sulphuric acid may produce toxic gases when heated in a fire situation. If fumes are inhaled, severe irritation to the throat will occur. Over exposure may result in mucous membrane irritation, coughing, bronchitis, ulceration, bloody nose, lung tissue damage, chemical pneumonitis, pulmonary oedema and death. Contact with skin may result in rash, dermatitis, blistering, severe burns and discolouration.

Sulphuric acid is classified Class 8 Corrosive for transport purposes.

For this Project, the sulphuric acid will be stored in a 10 000 te tank at the general process plant area of the mine site. This tank would be bunded and separated from other non-compatible chemicals to minimise the possibility of adverse interactions.

3.2.3 Sulphur Oxides

Sulphur dioxide and sulphur trioxide would be produced within the sulphuric acid plant at the mine site. Sulphur dioxide would also be produced in the flare stack associated with the hydrogen sulphide plant at the mine site. In the sulphuric acid plant, sulphur dioxide is formed by the combustion of sulphur in a burner. The sulphur dioxide is catalytically converted to sulphur trioxide in a fixed bed reactor. The sulphur trioxide is absorbed in weak acid to produce sulphuric acid.

Both gases are toxic but non-combustible.

Sulphur dioxide is a colourless gas with a characteristic pungent and suffocating odour. The TWA (Tome Weighted Average – concentration) is 2 ppm and the STEL is 5 ppm. Repeated exposure to the gas (>10 ppm) may cause lung effects including constriction and inflammation of the lungs and reduced lung function. It is an air contaminant and a constituent of smog. As the gas is heavier than air, it can accumulate in sumps, pits etc. In the presence of moisture, sulphur dioxide will form sulphurous acid (H_2SO_3) which is corrosive.

Sulphur trioxide, on release, will react with water in the atmosphere and form a dense cloud of visible (white) acid mist. The mist is likely to contain submicron droplets which remain airborne until they absorb additional water and rain out or are deposited onto surfaces. With regard to the effects of the acid mist formed, an LC_{50} (lethal concentration for 50% mortality) of 60 mg/m^3 for a 60 minute exposure is typical of most reported data.

3.2.4 Hydrogen

Hydrogen is a highly flammable and explosive gas which must be handled with care. It forms an explosive mixture with air over a wide range (4% to 75% v/v) and has an autoignition temperature of 585°C. The minimum ignition energy for hydrogen is 0.02 mJ which is extremely low. Hydrogen is known to self-ignite under certain conditions, e.g. high pressure letdowns or where static can occur.

Hydrogen burns in air with an invisible flame giving no warning of its presence. Hydrogen is the lightest gas (SG relative to air is 0.0695) and it diffuses rapidly through materials which are leak tight with air, nitrogen or other common gases. This low density, however, also ensures rapid dispersion following a leak. This significantly reduces the likelihood of unconfined explosions.

Hydrogen accumulation in confined spaces represents a significant explosion hazard. The mine site plant areas that would process hydrogen would be open and hence allow leaked hydrogen, from any source, to dissipate.

Hydrogen has no toxic properties; it is a simple asphyxiant.

Hydrogen fires could result following leaks from pipes or fittings. However, for low pressure applications, historical evidence suggests the likelihood of hydrogen fires is low. For high pressure applications, such as hydrogen storage bullets (pressures of approximately 180 barg), leaks have been known to ignite. Such high pressure systems will not be present at any of the Project component sites. Also, there will be no hydrogen storage facilities. The hydrogen produced at the mine site would be contained within piping and associated equipment until consumed in the hydrogen sulphide plant.

3.2.5 Hydrogen Sulphide

Hydrogen sulphide is a poisonous, toxic and corrosive gas with a ‘rotten egg’ odour. The odour threshold is at 0.13 ppm. At low temperatures or under high pressure, hydrogen sulphide may appear as a colourless liquid.

Hydrogen sulphide has a flammable range in air of 4% to 44%. It decomposes on heating to emit toxic fumes including those of SOx. At high concentrations, hydrogen sulphide burns in air to form water and sulphur. At low concentrations, it forms water and sulphur dioxide when burnt.

Hydrogen sulphide is a strong reducing agent and is highly reactive. It will react violently with oxidising agents (eg peroxides and nitrates) and corrodes metals to form metal sulphides.

Burns may result on contact with skin or inhalation. The TWA for hydrogen sulphide is 10 ppm (14 mg/m^3) and the STEL is 15 ppm (21 mg/m^3). At low concentrations of hydrogen sulphide (50 to 500 ppm) irritation of the mucous membranes and respiratory tract can occur. At higher concentrations (600 ppm) nausea, dizziness and oedema occur. The concentration identified as dangerous for periods of half to one hour is 400-700 ppm. Prolonged exposure at 250 ppm can result in pulmonary oedema (build up of fluid in the lungs). Lethal hydrogen sulphide toxicity following inhalation of 1000 to 2000 ppm paralyses the respiratory system and breathing ceases. Loss of sense of smell can occur at concentrations of 150 to 200 ppm.

Hydrogen sulphide is classified as a dangerous good for transport purposes and must be stored in a dry, cool place with good ventilation. Storing hydrogen sulphide in the proximity of strong oxidising agents, acids and heat sources should be avoided. For this Project, there are no storage facilities for hydrogen sulphide. As well, it would be processed in well ventilated areas away from non compatible materials.

3.2.6 Oxygen

Oxygen is not flammable but it strongly supports combustion (ie when concentrations are greater than 25%). This includes the combustion of steels as well as softgoods such as plastics and rubbers.

The hazards of producing and storing oxygen are well understood by all the global oxygen manufacturers. In summary, oxygen promoted fires can occur due to the following main circumstances:

- The presence of hydrocarbons within oxygen systems
- Adiabatic heat of compression
- Velocity related ignitions such as particle impact generating local hot spots

To minimise the risk of oxygen promoted fires, good design (eg choosing the correct materials of construction and restricting velocities through pipes etc.) and good maintenance practices (eg dedicated clean rooms for valve and equipment maintenance) are necessary. For this Project, the intention is to have an established oxygen manufacturer build, own and operate the air separation unit. Given the knowledge of existing oxygen manufacturers about the hazards of oxygen promoted combustions, the risk of oxygen fires is minimised to levels currently existing throughout Australia and overseas.

3.2.7 Chlorine

Chlorine is a toxic greenish yellow gas or amber liquid with a pungent and irritating odour. It is toxic by inhalation and is irritating to the skin, eyes and respiratory system. The threshold limit value for chlorine in terms of TWA is 0.5 ppm whilst the STEL is 1 ppm.

Chlorine is corrosive and only slightly soluble in water. It is an oxidising agent and may assist combustion. Violent reactions occur with many organic materials such as mineral oils, greases, silicones and finely divided metals. It also forms explosive mixtures with alcohols, glycols, ammonia and its compounds. Chlorine will also form an explosive mixture with hydrogen over a wide range of concentrations.

Although non-combustible, chlorine will support the combustion of other materials. Therefore, to avoid hazardous events when transporting or during storage, chlorine should not be loaded with explosives (Class 1 – as defined by the Australian

Dangerous Goods Code), flammable liquids (Class 3), spontaneously combustible substances (Class 4.2), dangerous when wet substances (Class 4.3), oxidising agents (Class 5.1) organic peroxides (Class 5.2), radioactive substances (Class 7), food and food packaging.

For this Project, chlorine would be brought onto the mine and quarry sites in robust cylinders from the suppliers for water treatment purposes. The cylinders contain only 68 kg of chlorine. This is typical of water treatment facilities throughout Australia and of low risk due to the robustness of the cylinder design and minimum use of piping and joints between the cylinder and the injection point to purify the water.

3.2.8 Diesel

Diesel is a mixture of hydrocarbons, including polycyclic aromatics (PAHs) and has a specific gravity at 20°C in the range of 0.82-0.87. It is used as a general chemical and fuel. At ambient conditions it is a clear to straw coloured liquid with a hydrocarbon odour. It has a boiling point of >149°C and a vapour pressure at 20°C of 0.067 kPag.

Diesel has a flash point of >63°C and is thus a combustible rather than flammable liquid. Diesel may form flammable vapour mixtures with air and has a flammable range in air of 0.6 to 7.0%. At ambient conditions (20°C) the saturated vapour pressure gives an equivalent concentration in air which is significantly below the lower flammable limit. Diesel fires should be extinguished using foam or dry agent extinguishers (carbon dioxide or dry chemical powder). On burning, diesel will produce toxic fumes, including carbon monoxide, and fire fighters should wear self-contained breathing apparatus if there is a risk of exposure to vapours or combustion products.

Diesel should be stored in well ventilated areas. It should be stored away from halogens, strong acids, alkalis, oxidising agents and foodstuffs. It is harmful if swallowed and may cause nausea, vomiting and depression of the central nervous system. Inhalation of diesel fumes can result in headaches, dizziness and possible nausea. Inhalation of high concentrations can also produce central nervous system depression, which can lead to loss of coordination, impaired judgement and if exposure is prolonged, unconsciousness.

Diesel is classified as a C1 (combustible liquid) for the purposes of storage and handling but is not classified as a dangerous good by the criteria of the Australian Dangerous Goods Code for transport by road or rail. Given the proposed storage type (closed tanks) and use of diesel on the mine, rail siding and quarry sites (eg fuel for trucks, fire water pumps etc), the most likely scenario will be pool fires if it is released and ignited. As it is not used at elevated temperatures, explosions involving diesel are not credible.

3.2.9 Diluent and Natural Gas

The diluent used in the solvent extraction processes is a Shellsol product. Like diesel, it is a combustible liquid and stored in a closed tank. As such, the most likely scenario will be pool fires if it is released and ignited.

Natural gas is piped to various users throughout the site, eg sulphur burner, hydrogen sulphide flare, steam and power plant and the hydrogen plant. As natural gas is primarily methane, leaks into unconfined areas can be expected to disperse safely based on historical evidence (Ref 5).

However, nearby sources of ignition and confinement increase the risk of either torch fires, flash fires and/or vapour cloud explosions. The latter two events are from a delayed ignition of a flammable gas cloud. Effects from the torch and flash fires result from radiant heat impact, and blast overpressure effects result from vapour cloud explosions. Typically, good piping design and effective maintenance and inspection procedures are sufficient to achieve acceptable levels of risk associated with these events.

3.3 Hazardous Incidents

3.3.1 Main Ore Processing Plant

To determine the possible significant hazardous events associated with the main ore processing plant, a one day hazard identification exercise was conducted in Perth with representatives from Black Range, SHE Pacific, Resource Strategies and SNC – Lavalin (the design contractors) present. This exercise was conducted as per the requirements of SHE Pacific's / Orica's Hazard Study 2 (Ref 6). The results are summarised in Table 4.

Table 4 – Hazard Identification for the Main Ore Processing Plant

Possible Hazardous Event	Possible Initiating Events	Possible Consequences	Prevention / Protection Measures
Dust release from stockpiles	Wind blown	Siliceous geothite ore is 20-30% silicon (processed in plant after year 5) Dust release could lead to silicosis issues	Water sprays on stock piles and hoppers Dust suppressant used
Loss of process water to scrubber in high pressure acid leach (HPAL) area	Pump fails, closed valve etc	Acid mist, steam and particulates released "Red mud rain" Local effects only due to low flow and concentrations Operator exposure	Low velocity release (<2 m/s) Process alarms and trips Operation monitoring by operators
Release of sulphuric acid (either feed acid or an acidic ore solution)	Loss of autoclave seals due to corrosion, erosion (high acid velocities), weld / fabrication defect, loss of seal cooling water etc Pipe break or equipment failure due to corrosion etc Diaphragm pump failure (HPAL feed pumps), eg corrosion in the casing Tanks or vessels overfilled	Loss of containment of sulphuric acid or acidic ore solution Possibility of local spraying of acid with acid mist generation (local event only) Operator exposure	Pressure vessels designed to AS 1210 Piping designed to relevant piping codes, eg ANSI B31.3 All plant areas processing sulphuric acid or acidic ore solution are bunded (either concrete or earth) Concrete bunded areas are lined (acid resistant) Bund volumes are sufficient to contain entire acid hold-up volumes within equipment and piping Pipes designed for low fluid velocities to avoid acid erosion problems

Possible Hazardous Event	Possible Initiating Events	Possible Consequences	Prevention / Protection Measures
			Bund sump pumps installed to pump lost acid to the CCD circuit for neutralisation prior to delivery to tailings Acid supply can be stopped by closing double isolation valves Leaks from pipes carrying acid or acidic solutions outside of bunded areas flow to the dirty water pond (lined) for treatment (eg can be pumped back to the CCD circuit) Correct materials of construction
Lifting PSV on HPAL autoclave	Autoclave overfill	Pressurised release of steam and acid	PSV vented to a safe location Delivery pumps unable to achieve PSV set pressure Instrumentation monitoring, including alarms, warning operators of the likelihood of lifting the PSV Containment philosophy as above
Internal explosion in acid storage tanks	Build-up of hydrogen due to acid reacting with metals, ignition from static etc	Equipment damage Release of acid Operator exposure Possibility of “missiles”	Tanks and process vessels are continuously vented Containment philosophy as above
Vapour release from CCD thickeners	Water vapour generated due to water temperature (70^{o}C)	Odour Steam plumes, mist clouds	Localised release only, no off-site impacts
Carbon dioxide release from Leach Residue Neutralisation Tanks	Neutralisation with limestone generates carbon dioxide (a simple asphyxiant)	Carbon dioxide could fill sumps, pits etc, thereby reducing the oxygen concentration	Dispersion of carbon dioxide due to height of release Confined space entry procedures which include oxygen monitoring

Possible Hazardous Event	Possible Initiating Events	Possible Consequences	Prevention / Protection Measures
Rupture of tailings pipe	Erosion Corrosion Water hammer	Spillage to ground leading to soil and groundwater pollution	High integrity pipe design Instrumentation to be installed to detect loss of flow (with automatic shutdown) On-site effect only due distance to boundary (2.5 km) Spill response procedures
Loss of containment from tailings dam, surge dam or evaporation pond	Wall failure	Environmental effects (pollution off-site)	Conformance to dam safety regulations Dams and pond designed for minimal leakage rates Monitoring bores and toe drains used Can transfer between dams and pond
Hydrogen sulphide release	Loss of containment from sulphide precipitation vessel due to corrosion, seal water failure etc Supply header failure (eg supplying the pre-reduction mixer in the neutralisation area or the copper reduction mixer in the impurity removal area) or flare supply system failure (including the supply line, knockout pots and pumps, and flare stack)	Atmospheric pollution Toxic effects, eg to humans Depending on size of release, possibly a torch fire from the leak point, or a flash fire or vapour cloud explosion due to delayed ignition	Instrumentation monitoring to warn of impending conditions for a release Gas detectors installed locally (automated shutdown of hydrogen sulphide plant) Plant layout minimises pipe run lengths Routine maintenance to ensure piping and equipment reliability Low pressure in flare system thereby minimising release rate Fire protection system, eg hydrants, to minimise the effects of a fire (contaminated firewater contained on-site)
Hydrogen sulphide release	Loss of flare due to, say, natural gas failure	As above Note: Flare stack 80 m high and rate is approximately 200 000 m^3/hr (10% hydrogen sulphide plant rate)	Robust flare management system Tall stack with a 60 m sterile zone around stack

Possible Hazardous Event	Possible Initiating Events	Possible Consequences	Prevention / Protection Measures
			4 pilot burners to be installed at the top of the stack Automatic shutdown of the hydrogen sulphide plant on loss of flare etc, thereby minimising the amount released
Natural gas fire (natural gas supplied to hydrogen sulphide flare)	Leak from piping (hole or rupture), valves, flanges, etc. due to impact, mechanical damage, corrosion, stress	Immediate ignition – local torch fire Delayed ignition – flash fire or vapour cloud explosion (explosion overpressures generated) Equipment damage Injury to personnel	Piping design to appropriate codes and standards, eg ANSI B31.3 Routine maintenance and inspection procedures Fire protection system, eg hydrants
Explosions within tanks and process vessels that contain hydrogen sulphide	Loss of nitrogen padding / purging Hydrogen sulphide concentration enters the flammable region and a source of ignition ignites the vapour	Material released, eg acidic solution Equipment damage Operator exposure Possibility of “missiles”	Gaseous nitrogen system backed up by a liquid nitrogen system Tanks to be sealed and earthed Electrical hazardous area safeguards Tanks to be purged of oxygen after maintenance Control of ignition sources, eg dematched areas (eg cigarette lighters not permitted in hazardous areas), hot work permits Explosive energy from gas phase only (relatively small volumes), therefore unlikely to have significant off-site over-pressure effects Instrumentation monitoring of the nitrogen supply system Vents to flare
Hydrogen sulphide release from the H_2S Recycle Compressor (in the sulphide precipitation area)	Seal leak, pipe leak, casing corroded	Effects as above for other hydrogen sulphide releases	As above for other hydrogen sulphide releases System can be vented to flare

Possible Hazardous Event	**Possible Initiating Events**	**Possible Consequences**	**Prevention / Protection Measures**
			Appropriate materials of construction System automatically purged with nitrogen at startup
Overfilling a sulphide precipitation autoclave	Level control instrumentation failure	Vessel filled, liquid to flare system	Centrifugal pumps feeding the autoclave cannot deliver the head necessary for vessel overpressurisation Knock-outs pots with level indication / alarms on the inlet line to the flare.
Combustion of nickel cobalt sulphide precipitate	Nickel cobalt sulphide precipitate dries out and ignites	Self heating or ignition leading to combustion (with sulphur dioxide released) Local effects only	Nickel cobalt sulphide precipitates stored under controlled conditions on a separate pad away from flammables etc Operator surveillance of storage conditions, ie monitoring moisture levels
Belt fire on conveyor (eg Sulphide Filter Discharge Conveyor)	Overheating of belt at pulley	Belt fire only (eg the filter concentrate is too wet to burn)	Anti-slip protection on belts Routine maintenance and inspections Fire protection, eg hydrants (contaminated firewater contained on-site)
Internal fire in Sulphide Leach Autoclave	Loss of dilution water	Fast, exothermic reaction leading to vessel damage, possibly an explosion	Water provided from two sources, each with separate controls (eg density meter to control flowrate) Should one water source fail, the other can supply the necessary water rate Oxygen supply stopped on upset conditions, thereby starving the reaction Maintenance of instruments, particularly critical alarms and trips

Possible Hazardous Event	Possible Initiating Events	Possible Consequences	Prevention / Protection Measures
			Pressure relief on vessel (with a blast spool to limit velocity of release)
Oxygen promoted combustion of pipe etc	Residual hydrocarbons, dirt (eg scale) or adiabatic heat of compression	Intense local fire of short duration Equipment damage most likely outcome unless personnel nearby (injury)	Pipe fittings to prevent reverse flow into the oxygen supply header from the Sulphide Leach Autoclave (eg non return valve) Maintenance of oxygen system to 'oxygen clean' standards Materials of construction compatible with oxygen Piping design (eg limit oxygen velocities)
Mist evolved from the pregnant leach liquor iron removal tanks	Open tanks, vapour can enter atmosphere	Mist containing trace quantities of nitric acid	Local event only due to minor amounts of acid Correct materials of construction to prevent corrosion All liquid spills contained within bunding
Loss of containment of the diluent (Shellsol) in the solvent extraction or storage areas and subsequent fire	Pipe or vessel leaks Pipe breakage Flange failure Pump leaks (eg seal failures) Tanker transfer hose failure Tanker driveaway Vessel overflows Hot pump bearing	Pool fire if liquid is ignited Products of combustion (eg carbon oxides, water)	Hazardous area controls (eg minimisation of ignition sources) Fully bunded area (Shellsol storage tanks to AS 1940) Fire protection and suppression systems (eg foam for pool fires and heat activated foam-water deluge system) Contaminated firewater contained on-site Routine maintenance to detect probable leak points Operator control and instrumentation monitoring

Possible Hazardous Event	**Possible Initiating Events**	**Possible Consequences**	**Prevention / Protection Measures**
Carbon bed fire (solvent extraction area)	Organics absorbed onto the carbon with oxygen and a source of ignition present (eg maintenance activity)	Smouldering type fire, possibility to propagate to a Shellsol pool fire	Control over ignition sources during maintenance Routine operations unlikely to cause fires (no oxygen present in enclosed system) Infrared detection system (sprinkler system to deluge automatically) Foam fire suppression system
Surfactant used in the nickel electrowinning area (sodium lauryl sulphate) is combustible and could be involved in a fire	Dry surfactant is exposed to a large ignition energy source (eg open flame)	Local fire involving surfactant Minimal risk of propagation	Control of ignition sources Surfactant comes as a paste to site Area processing surfactant is contained Fire protection system, eg hydrants, extinguishers
Confined explosion within electrowinning tankhouse	Steam, oxygen and hydrogen evolved from electrowinning cells, collects in ceiling and is ignited	Explosion Damage to building Possibility of “missiles”	Hydrogen concentration evolved from the cells is only 0.1% (ie below the lower explosion limit) Accumulation in the ceiling is prevented by cross-flow ventilation fans
Acid mist in electrowinning tankhouse	Mist generated by vapours rising from electrowinning cells	Local occupational health issues to operators	Ventilation fans and monitors to be installed PPE for operators Vent from tankhouses, historically, does not pose serious risks, either on or off site
Nitrous oxide emission from Nitric Acid Wash Tank	Agitation within tank or filling of tank	Release of small amount of vapour through the vent stack expected	Dispersion of vapours from top of stack Nitric acid is infrequently used in small volumes only Local occupational health issue only, operators to monitor

Possible Hazardous Event	Possible Initiating Events	Possible Consequences	Prevention / Protection Measures
Loss of vacuum in the Cobalt Degassing Furnace	Degassing Furnace Exhaust Fan and/or Degassing Furnace Vacuum Pump failure	No extraction in the Degassing Furnace Hydrogen concentration could build up within the furnace.	Explosion unlikely given the very small levels of hydrogen degassed out of the cobalt Three vacuum pumps are proposed, therefore providing redundancy Operator training and awareness
Pool fire at API water-oil separator	Oil, diesel runoff to API separator is collected and a source of ignition is present	Pool fire involving oil etc	Only combustible materials are collected in separator (low ignition risk) Electrical hazardous area safeguards Control of ignition sources, eg dematched site policy API separator isolated from other plant items (no propagation risk) Local event only – no off-site fire effects

3.3.2 Steam and Power Generation

The following hazard identification (Table 5) is based on typical plant designs as would be employed for the Project. The assumptions made in this analysis should be verified in the Final Hazards Analysis.

Table 5 - Hazard Identification for the Steam and Power Plants

Possible Hazardous Event	Possible Initiating Events	Possible Consequences	Prevention / Protection Measures
Natural gas release from pipe or fittings outside roofed areas	Leak or failure of pipe or fittings due to: • corrosion • impact • fire/explosion • earthquake • fabrication fault	Torch fire (resulting from immediate ignition) Flash fire or explosion (resulting from delayed ignition)	Piping design (material specification, fabrication testing) and inspection Painting Pipe located away from impact sources Control of ignition sources Isolation of supply
Natural gas release from pipe or fittings inside roofed area	As above	Fire (explosion possible if gas is trapped in confined space) Damage to building Possibility of "missiles"	As above, plus, where possible, plant design and layout will encourage the dispersion of gas leaks
Steam or condensate leak	Leak or failure of pipe or fittings due to: • corrosion • impact • fire/explosion • earthquake • fabrication fault • erosion • high temperature creep	Scalding, impact damage	Piping design (material specification, fabrication testing) and inspection Pipe sections buried, other sections to be located away from impact sources Isolation of supply Control of outlet steam quality Visible nature of small leaks (allowing corrective action for small leaks)
Turbine exhaust gas leak from casing	As for steam leak	Burns Asphyxiation Fire	Materials specifications, design and construction codes, correct installation, post fabrication testing Location away from impact sources

Possible Hazardous Event	Possible Initiating Events	Possible Consequences	Prevention / Protection Measures
			Routine inspection and maintenance Carbon dioxide extinguisher system Local effects only
Mechanical failure of a gas turbine	• Overspeed • Corrosion • Erosion • Fatigue/creep • Impact • Bearing failure • Lubrication failure • Deposition • Fabrication failure • Combustion zone explosion • Earthquake • External fire	Impact damage, hot gas escape, fire, burns, hydraulic oil escape	Robust automatic control and trip system Materials specifications, design and construction codes, correct installation, post fabrication testing Air and gas filtration Robust, proven casing designs Gas purity control
Mechanical failure of the steam turbine	As above for gas turbines	Impact damage, scalding	As for gas turbine except, • Erosion prevented by steam quality control and trip system • Deposition: high quality demineralised water used
Mechanical failure of boilers (heat recovery steam generator or auxiliary boiler)	• Relief system failure • Corrosion • Erosion • Impact • Fabrication failure • Combustion zone explosion • Earthquake • External fire or explosion	Impact damage, burns scalding	Routine maintenance and testing Materials specifications, design and construction codes, and correct installation Demineralised water quality, air and gas filtration Location and guard rails Automatic control and trip system Fire fighting systems

Possible Hazardous Event	Possible Initiating Events	Possible Consequences	Prevention / Protection Measures
Mechanical failure of diesel generators	• Overspeed • Corrosion • Impact • Bearing failure • Lubrication failure • Fabrication failure • Earthquake • External fire or explosion	Impact damage, fire	Routine maintenance and testing Materials specifications, design and construction codes, and correct installation Location and guard rails Automatic control and trip system Fire fighting systems
High NO_x/hydrocarbon emissions	Burner control system failure Wrong gas composition	Violation of EPA licence conditions with consequent penalties Plant operations restricted	Trip and alarm testing QA on gas supply Machine performance monitoring
High voltage electrical cables damaged/ broken	Excavation Storm damage Earthquake Subsidence	Electrocution/ shock to persons coming into contact Local fires	Specification, design and location of cable carrying facilities Correct excavation procedures followed Rapid disconnection of supply on fault Fire protection system
Loss of containment of diesel fuel (5 000 L tank) or lubricating oils	Impact Tanker, hose, or storage vessel failure Tanker driveaway Handling error Overfilling Corrosion Pipe leaks	Diesel contained by bunding Pool fire (if ignited) Oil mist fire could result if hot oil mist forms and is ignited	Inspection and maintenance procedures Materials specification Operator training Instrumentation monitoring of tank levels etc Control of ignition sources Fire fighting systems

Possible Hazardous Event	**Possible Initiating Events**	**Possible Consequences**	**Prevention / Protection Measures**
Loss of containment of transformer insulating oil	Impact Overpressure due to overheating (eg due to electrical problem) inside transformer casing External fire Transformer explosion due to major electrical fault or lightning strike	Pressure released via vent causing spillage (contained by bunding) Pool fire if ignition source present or ignited by or after an explosion	Guard rails, suitable location away from likely impacts Routine electrical maintenance Control of ignition sources Appropriate electrical design to minimise the effects of lightning and electrical disturbances Fire fighting systems

3.3.3 Industrial Gas Plants

The following hazard identification (Table 6) is based on typical plant designs as would be employed for the Project. The assumptions made in this analysis should be verified in the Final Hazards Analysis.

Table 6 - Hazard Identification for the Industrial Gas Plants

Possible Hazardous Event	Possible Initiating Events	Possible Consequences	Prevention / Protection Measures
Air Separation Unit			
Oxygen promoted combustion of pipe etc	Residual hydrocarbons, dirt (eg scale) or adiabatic heat of compression	Intense local fire of short duration Equipment damage most likely outcome unless personnel nearby (injury)	Maintenance of oxygen system to industrial gas standards Materials of construction compatible with oxygen Piping design (eg limit oxygen velocities) Inlet air monitoring for impurities Inlet air absorption guard beds
Condenser – reboiler explosion in the double distillation column	Build-up of hydrocarbons on the reboiler	Explosion within column, damaging column and surrounding cold box Possibility of “missiles”	Inlet air monitoring for impurities Inlet air absorption guard beds Bleed stream from upper column sump to purge impurities
Loss of containment of cryogenic fluid	Pipe or vessel failure Impact Leak through flange etc Leak from tanker transfer to storage, eg broken hose, bad connection	Concrete slabs underneath cryogenic handling equipment Liquid spills evaporate quickly due to rapid heat ingress Possibility of cold burns to operators	Plant design to industrial gas standards Operator training and procedures PPE
Hydrogen Production Plant			
Material failures due to hydrogen service releasing hydrogen, synthesis gas or PSA purge gas	Hydrogen embrittlement, metal dusting corrosion (blistering), stress cracking	Release of flammable gas Torch or flash fires, or explosions if ignited	Appropriate materials of construction Maintenance procedures include actions to be taken for hot work on hydrogen containing lines Gas detectors installed locally

Possible Hazardous Event	**Possible Initiating Events**	**Possible Consequences**	**Prevention / Protection Measures**
			Routine inspection and maintenance Minimum joints in piping design
Leaks of natural gas	Pipe or fittings failure Corrosion Impact etc	As above for hydrogen service failures	Appropriate materials of construction Gas detectors installed locally Routine inspection and maintenance Isolation of natural gas supply Flanges positioned to avoid impact on critical equipment Natural gas metering station secure from traffic etc impact Fire fighting systems
Internal explosion in reformer	Flammable gas present at startup	Equipment damage Possibility of operator injury Possibility of “missiles”	Robust burner management system to be used, including purging sequences Operator training and procedures
Hydrogen vent ignited	Static Lightning	Torch fire from vent pipe	Pipe vented to a safe location Nitrogen used to snuff out the flame Vent line can be isolated
Loss of level in process condensate pot prior to PSA beds	Valve failure Instrumentation failure	Process synthesis gas flow into the condensate system, potential for an internal explosion	Redundant instrumentation for back-up purposes Routine testing and maintenance procedures Operator vigilance on receiving alarm condition
High temperatures exit the desulphurisation vessel	High sulphur or carbon dioxide levels in the natural gas supply	Equipment failure leading to a release of natural gas	Natural gas supply is from the Moomba to Sydney line and its composition is rigorously controlled

Possible Hazardous Event	Possible Initiating Events	Possible Consequences	Prevention / Protection Measures
			Instrumentation monitoring and shutdown on gas stream hazardous conditions, eg high temperature Piping and vessel design temperatures
Flames from reformer box openings	Loss of fan pulling draught	Possible injury to operators in nearby area	Robust burner trip system shuts down reformer Routine testing of trips and fan
Plant shutdown explosion	On shutdown, air can be drawn into the shift converter	Overheating of the catalyst vessel Explosion of synthesis gas Possibility of “missiles”	Operating procedures including the padding of the all catalysts with nitrogen at shutdown
Hydrogen Sulphide Plant			
Material failures releasing hydrogen	Hydrogen embrittlement, metal dusting corrosion (blistering), stress cracking leading to a leak Impact Flange failure	Release of flammable gas Torch or flash fires, or explosions if ignited	Appropriate materials of construction Maintenance procedures include actions to be taken for hot work on hydrogen containing lines Gas detectors installed locally Routine inspection and maintenance Minimum joints in piping design
Release of molten sulphur	Pipe, fittings or vessel failure Corrosion Impact Reflux pump failures	Molten sulphur will cool upon release Spraying may form a mist that could ignite leading to a local fire	Appropriate materials of construction Routine inspection and maintenance Process area bunded thereby minimising the spread of sulphur Isolation of sulphur supply Sulphur transfer line secure from traffic etc impact Fire fighting systems

Possible Hazardous Event	Possible Initiating Events	Possible Consequences	Prevention / Protection Measures
Explosion within reactor	Inadequate purging of air from the reactor prior to startup. Hydrogen and sulphur introduced and an explosive atmosphere exists. Excessive reaction between hydrogen and sulphur leading to high temperatures	Equipment damage Release of hydrogen, sulphur and hydrogen sulphide Injury to personnel Possibility of "missiles"	Maintenance and purging procedures Controlled startup of plant Instrumentation monitoring and trip protection Isolation of hydrogen and sulphur supply lines minimising release quantities Operator training and procedures
Release of hydrogen sulphide	Pipe, fittings or vessel failure Corrosion Impact	Atmospheric pollution Toxic effects, eg to humans Depending on size of release, possibly a torch fire from the leak point, or a flash fire or vapour cloud explosion if delayed ignition occurs	Instrumentation monitoring to warn of impending conditions for a release Gas detectors installed locally (automated shutdown of hydrogen sulphide plant) Plant layout minimises pipe run lengths Routine maintenance to ensure equipment reliability Appropriate materials of construction Fire protection system, eg hydrants, to minimise the effects of a fire (contaminated firewater contained on-site)

3.3.4 Sulphur Handling and Sulphuric Acid Plant

Hazard identification for the sulphur handling and sulphuric acid plants (Table 7) is based on typical acid plant designs. The assumptions made in this analysis should be verified in the Final Hazards Analysis.

Table 7 - Hazard Identification for the Sulphur Handling and Sulphuric Acid Plants

Possible Hazardous Event	Possible Initiating Events	Possible Consequences	Prevention / Protection Measures
Release of sulphur dioxide or sulphur trioxide	Fugitive emissions from vessel holding hot molten sulphur Failure of stack fan Leak or rupture at acid plant due to mechanical failure or impact, eg suction seals, valves, blower, piping, vessel or heat exchanger, transport or cranage accident Loss of absorption in acid plant absorption tower, eg loss of reflux liquid	Release of sulphur dioxide or sulphur trioxide at ground level or through the stack Toxic gases are dispersed Acute effects only (no long term effects) Corrosion of nearby structures	Regular maintenance Computer control of the acid plant Operator training and surveillance Automatic shutdown of plant on upset conditions Sulphur dioxide monitors located throughout the plant Mechanical protection of the plant from traffic etc, eg bollards, walls Appropriate materials of construction Visual indication of release (white plume)
Release of sulphuric acid	Leak at piping, valves, pumps and associated equipment inside storage tanks bund or within the acid plant boundary (impact, mechanical damage, corrosion, erosion) Sample point left open Tank overfill Damage to pumps from running against a closed head Dry pump damage Loss at tanker unloading bay (used at initial plant startup and periods of high acid demand)	Release of acid forming pools inside bunds Personnel injury if in contact If water added, production of fumes and heat Explosive reactions with non-compatible materials	Bunds can contain volume of acid within plant equipment and tanks. Also, the tanker unloading bay is a contained area Spills can therefore be neutralised prior to pumping away Storage tanks to be fitted with high level instrumentation Operators will be trained in safe handling of products and use of protective equipment Periodic maintenance and control (manual and instrumented) of lines and pumps

Possible Hazardous Event	Possible Initiating Events	Possible Consequences	Prevention / Protection Measures
			Emergency response procedures to be prepared for handing spills Safety showers and eye wash stations to be installed Segregation from non-compatible materials (eg natural gas)
Development of hydrogen vapours in sulphuric acid pipeline or storage tanks	Corrosion of steel	Possibility of hydrogen embrittlement of the steel at high points Danger of ignition of hydrogen during maintenance etc	Protective coatings in tanks Acid strength is maintained (presence of water induces corrosion) Any hydrogen developed in the storage tanks will be vented away (via the tank vent) Hydrogen detection before maintenance Earthing of pipeline prevents excessive build-up of electrostatic charges
Natural gas fire (natural gas supplied to sulphur burner for startup purposes)	Leak from piping (hole or rupture), valves, flanges, etc. (impact, mechanical damage, corrosion, stress)	Immediate ignition – local torch fire Delayed ignition – flash fire or vapour cloud explosion (explosion overpressures generated) Equipment damage Injury to personnel	Piping design to appropriate codes and standards, eg ANSI B31.3 Routine maintenance and inspection procedures Fire protection system, eg hydrants
Explosion in sulphur burner or downstream equipment	Incorrect burner startup sequence Sulphur entrainment from the burner	Build-up of natural gas and/or sulphur in burner prior to ignition Explosion when ignition takes place Equipment damage Injury to personnel Possibility of “missiles”	Robust, proven burner management system to be used Operator training in startup procedures Purging cycles to avoid the build-up of flammable atmospheres Most likely outcome – energy of explosion damaging local equipment only

Possible Hazardous Event	Possible Initiating Events	Possible Consequences	Prevention / Protection Measures
Sulphur fires	Ignition source at stockpiles, eg front end loader, hot ash from diesel engines, or at the molten sulphur tank area	Sulphur fire evolving sulphur oxides	Stockpile wetting and control Small fires typically extinguished by smothering (in some cases by adding more sulphur on top to starve the fire of oxygen) Larger fires can be flooded with water Operator training and vigilance (smell is a very early indicator of sulphur fires) Front-end loaders safety features include spark arrestors on the exhausts and heat protection around the engines

3.3.5 Fuel Farm and Caustic Soda Storage

Hazard identification for the fuel farm and caustic soda storage (Table 8) is based on typical plant designs. The assumptions made in this analysis should be verified in the Final Hazards Analysis.

Table 8 - Hazard Identification for the Fuel Farm and Caustic Soda Storage Areas

Possible Hazardous Event	Possible Initiating Events	Possible Consequences	Prevention / Protection Measures
Fuel Farm			
Loss of containment of diesel fuel from a 50 000 L tank (vehicle filling) Note: The diesel supply tank (5 000 L) for the emergency generator was included in the steam and power plants section. Loss of containment from the 1 000 L tank (firewater pump) as per the 5 000 L tank but with smaller effects	Impact Tanker, hose, pump, bowser or storage vessel failure Tanker driveaway Handling error Overfilling Corrosion Pipe leaks	Diesel contained by double lined tank or bund walls Pool fire (if ignited)	Inspection and maintenance procedures Materials specification Operator training Instrumentation monitoring of tank levels etc Control of ignition sources Fire fighting systems
Caustic Soda Storage			
Loss of containment of caustic soda	Impact Tanker, hose, pump or storage vessel failure Tanker driveaway Handling error Overfilling Corrosion Pipe leaks	Release of corrosive fluid (contained by bunding, including the tanker unloading area)	Inspection and maintenance procedures Materials specification Operator training Instrumentation monitoring of tank levels etc Spill response plans including neutralisation and disposal procedures

3.3.6 Transport Hazards

Rail

The preliminary road and rail transport plans for the majority of the materials brought to, and taken from the site are detailed in Section 2.5 of this report. All classified dangerous goods will be transported in accordance with the regulations as stated in the Australian Code for the Transport of Dangerous Goods by Road and Rail. There are no identified departures from these regulations for the proposed development.

For this development, rail transport primarily concerns the movement of sulphur from the stockpile in Newcastle, NSW, to the proposed rail siding. The proposed number of return train trips per week is approximately two (1 875 te of sulphur per trip). To avoid congestion in the Sydney rail network as well as steep grades in the crossing of the Blue Mountains (ie minimise the likelihood of an accident), it is proposed that trains to and from the site use a route via Muswellbrook, Ulan, Dubbo, Narromine and Parkes to Bogan Gate.

The significant hazards are the potential for the sulphur to catch alight and emit toxic fumes (eg sulphur dioxide) or generate a dust explosion (sulphur has a relatively low dust ignition energy and autoignition temperature). The sulphur could catch alight due to ignition whilst in transit (eg arson, lightning strike, static) or due to an accident involving the train.

Radiant heat effects due to burning sulphur are localised only. Any loss of containment during transport will be responded to as per the proposed emergency response plans for the site to avoid contamination of waterways etc.

Sulphur is classified as a flammable solid (4.1), Packing Group III (minor danger only). It is routinely transported in bulk around the world. Separation from non-compatible materials and elimination of ignition sources are the major measures taken to avoid incident.

Protection features for the bulk transport of sulphur by rail to the proposed siding include minimal dust in the bulk sulphur (prilled form), proposed water sprays at all transfer points, local fire brigades (for water application), electrics (such as motors) rated for the hazardous area zones, separation from non-compatible materials and static protection. Small fires can be smothered with sand or even with additional sulphur. The sulphur remains within the shipping containers until it is taken to the site.

Given the proposed protective features associated with the rail transport of sulphur, the low likelihood of ignition of sulphur within the containers and the accepted risk of transport of bulk sulphur by road or rail throughout Australia and the world, the overall risk of an incident involving sulphur with significant consequences during rail transport is considered low. No further analysis (ie quantification of risks) of the transport of bulk sulphur to this site is deemed necessary.

Caustic soda is proposed to be transported by road or rail. For the purpose of this study, rail transport has been assumed. As with the transport of sulphur, it is proposed to have two return trips per week via Parkes (approximately 250 to 300 te per trip). The caustic soda containers would be offloaded by forklifts and trucked to the mine in the same way as sulphur. The equipment to be used will be of international design and robust in nature (ie designed to withstand designated drops, impacts etc without release). As such, the likelihood of a release is low due to the transport equipment design, compliance with rail transport regulations and route selection.

Product metals and metal precipitates are also likely to be transported from the site by rail. This is proposed to be achieved by backloading containers bringing sulphur to the site. Thus, delivery of product will involve no extra road or rail movements. The mixed sulphide product will be stored and transported in 2 te bulka bags, not as a bulk concentrate. This significantly reduces the ability of the material to dry out or spontaneously combust, hence mitigating the risks to people, property or the environment.

Road

As stated in Section 2.5 of this report, the bulk chemicals likely to be transported to the mine site by road tankers are Shellsol (the solvent extraction diluent), diesel, liquid nitrogen and oxygen (for startup), magnesium oxide, hydrated lime, sulphuric acid (for startup and periods of high acid demand) and flocculant. Waste oil from the API separator is to be transported from the mine site by road tanker. The majority of the packaged chemicals (eg acids, bases and reagents in bulkiboxes, and, chemicals and catalysts supplied in drums, bulk bags or cylinders) are to be transported by road.

Chemicals transported by road would, where relevant, be transported in accordance with the Australian Code for the Transport of Dangerous Goods by Road and Rail.

The expected annual frequency of deliveries of bulk chemicals to the proposed development is given in Table 9. Note: Chemicals brought to the mine site for startup purposes only have been excluded.

Table 9 - Bulk Chemicals Transport Frequencies

Material Transported	Number of Return Trips to Site per Year
Shellsol (the solvent extraction diluent)	4
Diesel	150 (approx.)
Magnesium oxide	3 300 (approx.)
Hydrated lime	5
Flocculant	12
Limestone	10 000 (approx.)

Materials such as magnesium oxide, hydrated lime and limestone not are classified as dangerous goods for transport by road and rail and therefore are relatively safe to transport in bulk form (subject to road and rail usage regulations). Shellsol and diesel are both combustible liquids. The transport of these types of materials in approved road tankers throughout Australia is commonplace and of low risk.

The packaged chemicals delivered by road transport in bulkiboxes, drums, bulk bags or cylinders, again, will be transported in accordance with the Australian Code for the Transport of Dangerous Goods by Road and Rail. The main usage of these chemicals is for dosing systems, shutdown replacements, topping up storages etc. The small packaged volumes with low usage rates pose minimal transport risks due to loss of containment, fires etc. Mitigation of risks is also provided by the proposed use of approved transport companies through their safety management systems and emergency response plans.

It is noted that as a separate part of the EIS for this project, a transport study is being performed (Appendix C of the EIS). This study includes assessment of the proposed roads for the new traffic demands. In addition, Appendix C of the EIS presents mitigation measures such as restricted use of the materials transport route when school buses are operating. Also, noise impacts due to increased traffic are assessed in the noise report (Appendix K of the EIS).

Aircraft Impact

The site is remote to all major airports and congested flight path areas. Local aircraft activities mostly involve crop dusting (this is a seasonal activity). As such, there will not be significant numbers of aircraft (either scheduled or unscheduled) flying over the proposed development area.

The requirements of the hazardous nature of the proposed development need to be communicated to the local aircraft industry. However, given the rural location of the proposed development, the likelihood of any aircraft impacts onto the proposed site is small.

3.3.7 Natural Gas Pipeline Hazards

Natural gas will be supplied to the site from a lateral of the Moomba to Sydney gas pipeline. The majority of the pipeline run will be within the road reserve. The proposed gas pipe run is shown in Figure 1. It will be laid underground and setback a minimum safety distance from all residences in accordance with Australian Standard 2885 (Pipelines – Gas and Liquid Petroleum) and Australian Standard Handbook 105.

The pipe route has been selected (and modified several times) to avoid sensitive areas, thereby taking public safety into consideration. This includes routing the pipe around the outskirts of Condobolin.

The major hazards associated with the pipe are loss of containment from leaks (eg due to corrosion, mechanical damage) leading to fires (torch and flash) and explosions.

To reduce the likelihood of these events from occurring, the pipe is to be laid in accordance with the relevant standards and codes (eg AS 2885, Pipelines – Gas and Liquid Petroleum). Measures recommended in this standard to reduce the likelihood of loss of containment include burial to avoid damage from hostile events (eg sabotage), corrosion protection features (eg corrosion allowance on wall thickness, approved material of construction, cathodic protection), flow monitoring (by computer controls) and fracture control plans (including means of isolation), signage, deep burial and large wall thickness to protect against common digging activities (eg ploughing, digging, fence post drilling etc), and minimisation of joints (and hence hazardous areas for electrical equipment selection etc).

Given that the natural gas pipe is to be run to avoid sensitive areas, and will be installed with mitigation features as detailed in such standards as AS 2885, acceptable levels of risk result and further quantification of fires or explosions is not warranted.

With regard to the possibility of a vapour cloud explosion from a large leak of natural gas, Ref 5 states:

"*There is now considerable evidence that vapour clouds of methane at normal temperatures burn, but do not readily ignite. Many experiments have been done in which attempts have been made to initiate explosions in methane clouds, but in which no explosion occurred.*

The occurrence of vapour cloud explosions involving methane has been reviewed by V. C. Marshall. He cites expert opinion to the effect that there has been no case of an unconfined vapour cloud explosion with natural gas, but also the account given by Gugan of an 'explosion' involving methane at Raunheim, West Germany, in 1966."

The low reactivity of methane probably accounts for this historical finding. Realistically, releases of methane, if ignited, form flash fires with injury and damage mostly confined within the envelope of the cloud. The absence of sensitive areas adjacent to the pipe run reduce the risk from this event considerably.

3.3.8 Mining Operations (Ni-Co Ore and Limestone)

Where the nickel-cobalt ore is mined, the mining contractor is expected to have diesel storage of approximately 100 m^3 in two separate tanks. The tanks would be designed in accordance with AS 1940 (Ref 7) and hence will be fully bunded. The road tanker unloading area will also incorporate containment in case of a loss of diesel whilst unloading (eg hose failure, tanker driveaway). The diesel will be used to fuel earth moving machinery with the bowsers local to the storage tanks.

The distance from the mining contractor area (where the diesel will be stored) to the site boundary is in excess of 1 kilometre. Even if there was a spill of diesel with a pool fire resulting (most credible scenario), at this distance there will be no significant off-site effects due to radiant heat exposure. Also, the risk of propagation to other hazardous plant areas is negligible due to the large distance involved. Therefore, risks associated with the storage of diesel at the nickel-cobalt mining contractors area are deemed negligible and are not analysed further in this report.

Similarly, diesel will be stored at the limestone quarry, again for earth moving equipment. As per the nickel-cobalt mining contractors storage area, the facility will comply with AS 1940 and distance to the boundary negates any effects from radiant heat exposure. It should be noted too that diesel, being a combustible liquid, does not necessitate a need for hazard analysis as per SEPP 33 (Ref 8). This reflects the low risk imposed by correctly designed and operated facilities handling combustible liquids.

Explosives will be used at the limestone quarry to break up the ore. The use of explosives shall be as per standard mining and regulatory practice, eg detonators stored separately to explosive charges, purpose built storage facilities, static protection facilities, strict procedural control enacted by well trained personnel. Historically, these practices have proven to be adequate in avoiding unplanned explosions with off-site impacts. As such, the risk of a spurious explosion involving the explosives stored on the limestone quarry site is deemed to be negligible. This judgement is based on the assumption that the quarry site will have a quality safety management system in place and in use for the life of the facility.

3.3.9 Packaged Chemicals

There are a large number of packaged chemicals delivered by road transport to the site in bulkiboxes, drums, bulk bags or cylinders. Once on-site, there is potential for incidents such as localised fires and toxic releases. The volumes are small enough not to be involved in credible explosion events provided mixing of non-compatible chemicals is avoided.

As the bulkiboxes, drums, bulk bags or cylinders will be stored in approved storage facilities, or in dedicated, bunded (contained) areas, adequately separated from nearby hazardous plant and equipment, the risk of these local fires or toxic releases impacting off-site is negligible. As some of the chemicals stored in these small volume containers are very hazardous (eg nitric acid), adequate spill response procedures are required. These are to be prepared prior to commissioning.

With regard to the release of chlorine from a cylinder (leaking valve, corroded cylinder), previous work performed by SHE Pacific (Ref 9) shows that significant adverse effects are limited to approximately 100 m from the point of release. Given that the distance to the site boundaries are well in excess of this (eg approximately 1 kilometre at the mine site) it can be concluded that a release of chlorine has no significant off-site impacts.

3.3.10 Natural Hazardous Events

The site has been assessed with regard to exposure to the following external hazards:

Subsidence

Burst dam

Storm and high winds

Landslide

Earthquake

Rising water courses

Flood

Lightning

Vermin/insect infestation

Storm water runoff

Forest fire

Given the current proposed location of the Project components, there are no obvious significant hazards amongst this list that could result in on-site events leading to serious off-site impacts.

3.3.11 Hostile Events / Breach of Security

Hostile events and breaches of security include sabotage and trespassing. Measures which mitigate the likelihood of these events include permanent site security, fencing around the mine site, quarry and rail siding, restricted access within these sites and manned gate access to the mine and quarry site. These measures are typical of similar hazardous facilities throughout Australia.

4 CONSEQUENCE ANALYSIS

The proposed site layout shown in Figure 3 shows that the processing plant area lies well within the mine site boundary. Further details of the plant layout are shown in Figure 4.

The nearest mine site boundary is the Fifield to Wilmatha Road to the west. This is approximately 1 kilometre away from the centre of the processing plant area. The remaining boundaries in the north, east and south directions are in excess of 1.75 kilometres from the centre of the processing plant area. Also, whilst risk is calculated for the nearest off-site location, the nearest residence in the westerly direction from the mine site is more than 3 kilometres away from the processing plant. Effects due to most hazardous events at such large distances are normally low or negligible.

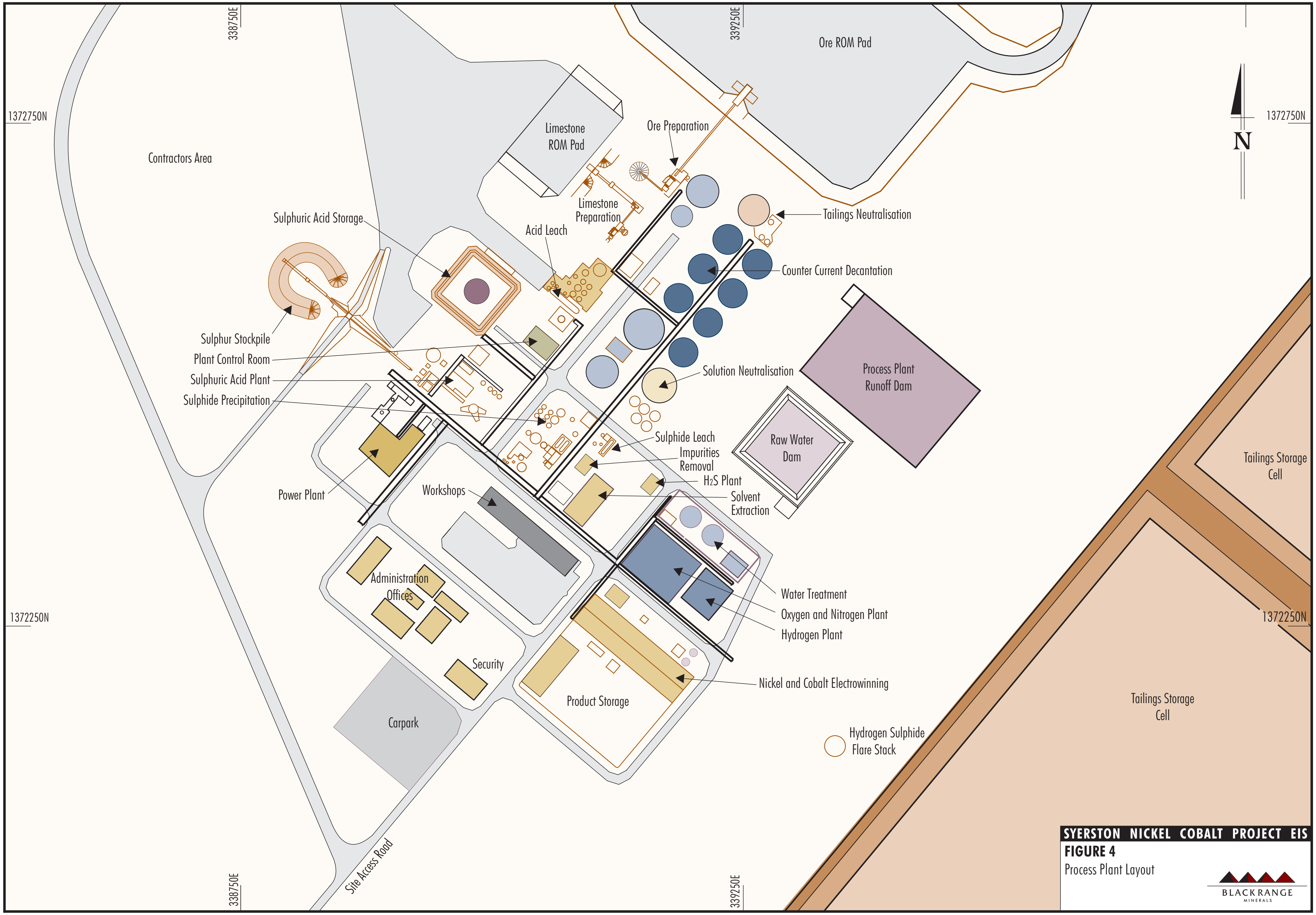
With regard to the limestone quarry, the proposed location of the diesel storage is in excess of 100 metres.

Given these large distances to the site boundaries, the assessment approach taken in this PHA is to analyse all incidents that may have an effect (eg irritation, injury, fatality) at the site boundary (as required by Refs 1 and 2). This approach is taken as the majority of identified incidents have no effect over such a large distance, eg a natural gas release from a flange leak at the processing plant, if ignited, will have no thermal effects at distances of 1 kilometre or more, and hence rigorous analysis is unnecessary. This approach will allow detailed assessment of, and hence draw attention to, the significant hazardous events. This approach will also aid in the determination of plant design requirements to mitigate the risks from these significant hazardous incidents, as well as influence the plants safety management systems and emergency response plans.

The consequence calculations in this PHA were carried out using commercially available risk assessment software, TNO's Effects v2.1 (Ref 10). The consequence models used within Effects are well known and are fully documented in the TNO Yellow Book (Ref 10). A brief listing of the models is given in Attachment 2.

Essentially, for each scenario defined by the analyst (eg those events considered significant and likely to have an impact at distances of 1 kilometre or beyond for the mine site), an appropriate release rate is calculated by using established equations within Effects. Data pertinent to the release conditions, including the initial state of the material, is included in the calculations.

Once the release conditions and rate have been determined, the likely outcomes (eg fire, explosion or toxic gas release) are modelled. The results from these simulations (eg radiant heat from fires, overpressure from explosions or plume concentrations from toxic gas releases) are used to determine the effect on people, property and/or the environment.



SYERSTON NICKEL COBALT PROJECT EIS

FIGURE 4

Process Plant Layout

BLACK RANGE MINERALS

The scenarios identified in Section 3.3 are the basis of the risk assessment. The significant events that involve fires, explosions and toxic gas releases are analysed further in this section. The basis for each analysis is given in the corresponding section to define the conditions of release for each event. This also includes assumptions made for each scenario.

Release Sources

For gas or liquid release scenarios, piping failures have been analysed using four failure cases. These are full pipe fracture, 50 mm, 13 mm, and 3 mm holes. Gasket failure is likely to result in a gap equivalent to the area between two flange bolts and is included in the analysis where relevant. This is considered equivalent to a 13 mm diameter hole size. Vessel failures have been analysed as catastrophic rupture and leaks of 50 mm, 25 mm, 13 mm and 6 mm. These generic failure cases are comparable to those used in a number of published risk assessment studies and described in Lees (Ref 5).

Release Rates

Release rates were calculated for each release scenario using standard equations based on hole size, pressure, temperature and material state (ie gas or liquid). Where the calculated release rate was greater than the maximum possible process rate (for example, if the flow was limited by the hydrogen sulphide production rate), the release rate was specified as equal to the limiting leak rate. The maximum release inventory was also limited to the contents of the plant equipment plus the amount lost over the duration of the leak (variable depending on the leak rate).

Release Duration

The assumed time taken to stop and control a release is based on a best estimate of a release scenario rather than always taking a worst case approach (in accordance with quantitative risk analysis principles).

For any scenarios where automatic shutdown of the plant occurs on detection of the hazardous event, a release duration of 1 minute has been chosen. This is consistent with the reported methodologies in Lees (Ref 5) and the approach taken within the SHE Pacific ISORIS risk assessment package (Ref 11). Also, if any worst case events occur (eg catastrophic rupture within the sulphuric acid plant where large visible clouds occur along with numerous alarms and trips) which are immediately obvious to the operators (24 hour manning), a release duration of one minute has been chosen.

For smaller leak scenarios which rely on manual response to stop and control the release (ie where operator intervention is required to stop the leak, usually by shutting down production or closing valves), release duration of between 6 and 30 minutes can be expected. The duration depends on the means to alert the operators of the release (eg process alarms) as well as the closeness of the release to the operators (ie smell, sight and/or noise may indicate a release if the operator is nearby). In this assessment, release duration for small leaks is assessed individually as described in the appropriate section.

Given that the plants are to be designed to the latest design standards which will include comprehensive monitoring via programmable electronic systems, it can be expected that sufficient alarms and trips will exist to warn the operators of significant abnormal plant behaviour. This expectation can be verified in the FHA and HAZOP studies if the project goes ahead. As such, the nominated release durations are judged to be achievable.

As a further means to mitigate the release duration (and hence release quantity), it is proposed to install emergency isolation valves (EIVs) on the inlets and outlets of all equipment processing the more hazardous materials (eg the sulphide precipitation vessels). Once a plant trip is initiated, these EIVs will shut, thereby boxing in sections of pipework and equipment. Hence, the amount released and the release duration are minimised.

For the sulphuric acid plant, shutting the plant down quickly stops releases as these plants run at low pressure (typically up to 24 kPag). Hence, there is little driving force for losses once the plant is stopped.

For any process plant, once the plant is stopped, the maximum amount released (and hence maximum duration) is limited by depressurising to atmospheric pressure if a pipe or vessel failure has occurred.

Meteorological Data

The meteorological data used in this PHA comprises the six dominant weather/wind combinations (Pasquill stability category / wind speed) for the area and has been used as the basis for all dispersion calculations. The probability of the relevant combined weather/wind category and wind direction (data is split into 16 directions) is used in the calculation of toxic impact at the nearest site boundary to the west of the processing plant.

The meteorological data used for this risk assessment is contained in Attachment 3. In general, the most stable meteorological conditions (F stability) lead to the largest effect distances for toxic release. Therefore, all dispersion simulations have been performed assuming F stability unless otherwise noted.

Terrain Effects

Ground roughness affects the turbulent flow properties of wind, hence dispersion of a released material. Terrain effects are taken into account in the dispersion modelling in this PHA by the use of a parameter known as surface roughness length.

The surface roughness length used in this PHA is 0.1 metre. This corresponds to farm land type terrain (eg airfields, agricultural land, fields with many trees) and is typical of the land in and around the site. No account is taken of the effect of plant structures enhancing turbulence, thereby reducing effect distances, in this PHA. Whilst this is a conservative approach, it is the concentrations at approximately 1 kilometre from the processing plant area that are of interest, hence the choice of 0.1 metre surface roughness length.

4.1 Gas Releases

The following gas release scenarios for the proposed plant are analysed within this section of the PHA:

1. Hydrogen sulphide releases

2. Sulphur dioxide releases

All other toxic gas release scenarios would not extend to the nearest mine site boundary and therefore are considered to have local impacts only.

4.1.1 Hydrogen Sulphide Releases

Hydrogen sulphide is produced in a reactor at the hydrogen sulphide plant and is piped directly to three separate areas. These areas are the sulphide precipitation vessels (two off, the largest user), the pre-reduction mixer (solution neutralisation area prior to sulphide precipitation) and the copper reduction mixer (impurity removal area). There is no storage of hydrogen sulphide other than the amount contained within piping and process vessels. Process vent streams are piped to the hydrogen sulphide flare for combustion of the hydrogen sulphide to sulphur oxides. These vent streams are close to atmospheric pressure.

All separate process units include EIVs in the piping that are closed by plant shutdowns, eg manually initiated or automatically by detection of hydrogen sulphide via gas detectors positioned around the relevant process units. Since it is proposed to automatically shutdown the plant on detection of a release of hydrogen sulphide (and hence close the EIVs) this will restrict the amount of hydrogen sulphide released.

Calculations were performed to determine the amount of hydrogen sulphide contained within sections of piping and equipment bounded by EIVs. For all areas processing hydrogen sulphide, the maximum released inventory of hydrogen sulphide from an isolatable section is calculated to be 360 kg (ie that can be released when the total system is depressurised to atmospheric pressure). This is assumed to be lost over a duration of 1 minute (realistic given calculated release rates). Consequence calculations, therefore have been initially performed on a worst case scenario of total loss of hydrogen sulphide contained in all the processing areas with production at full rate for 1 minute. Then, selected scenarios whose release rates are deemed high enough to have an impact at the site boundary are modelled.

Release conditions are summarised as follows:

Plant rate (ultimately restricts discharge rate)	62 te/day (0.72 kg/s)
Initial pressure (at the sulphide precipitation vessels)	9 barg
Temperature (approximate)	60°C
Release height (approximate pipe rack level)	5 m

Given this temperature, the density of the hydrogen sulphide when it is released to atmospheric pressure is calculated to be 1.25 kg/m^3. As this is approximately the same as air at 15^{o}C (1.23 kg/m^3), then the plume is treated as having neutral buoyancy and it is modelled by using the Gaussian neutral gas dispersion correlations (Ref 10). The model runs are based on a release duration of one minute (at full plant rate) plus release of the amount of hydrogen sulphide contained within either the total hydrogen sulphide system, or sections of piping and equipment bounded by EIVs.

For the scenario of catastrophic vessel failure (eg one sulphide precipitation vessel), the hydrogen production can be assumed to stop immediately as the fail safe trip system will trip the hydrogen sulphide plant. For small leaks (say, hole sizes of 13 mm or less), the small plumes may not be detected automatically. Hence, a 15 minute release duration is chosen to allow for the operators to detect the leak and manually shutdown the plant or isolate the supply.

Toxic Impact of Hydrogen Sulphide on Humans

The toxicity effects of hydrogen sulphide (Ref 5) on humans are summarised in Table 10.

Table 10 - Effects of Hydrogen Sulphide on Humans

Exposure Level (ppm)	**Duration**	**Effects**
0.13	Immediate	Odour threshold
50 – 500 70 –150	Not stated 3 – 4 hours	Irritation of the mucous membranes and respiratory tract occur, loss of smell (after 2 to 15 minutes)
70 – 300	1 hour	Maximum concentration inhalable without serious effects
600	Not stated	Nausea, dizziness and oedema
400 – 700	½ - 1 hour	Dangerous effects expected
> 1000	Within minutes	Lethal – paralyses the respiratory system

Toxicity effects resulting in fatality may be estimated using probit equations. For this PHA, the probit equation below (taken from the SHE Pacific HAZAN Course Notes, Ref 12) for hydrogen sulphide has been used. Of the probits analysed, it is regarded as the more conservative (ie it should over predict the likelihood of fatality – see Attachment 4 for details relating to hydrogen sulphide toxicity and the use of probit equations to predict toxicity effects on humans).

$$Pr = -40.35 + 2.90 \ln (C^2T)$$

Where C = concentration (ppm)

T = exposure duration (minutes)

The absolute values given in Table 10 form the basis for estimating the likelihood of exceeding irritation or injury risk criteria. The probit equation above provides the probability of fatality for a given toxic load (ie used for estimating individual fatality risk).

Toxic load for hydrogen sulphide is calculated within Effects by integrating the concentration at a particular location over the exposure duration. The concentration may vary over time depending on the type and duration of the release. The duration is the lesser of the time taken for the cloud to pass or the maximum exposure time (set to 1 hour in this study). The calculated toxic load is then used in the probit equation to estimate the probability of fatality at a particular location.

The approach adopted in this PHA is to calculate the toxic load at the nearest site boundary to determine if it exceeds the 1% fatality level for a number of significant release scenarios. If these scenarios do not exceed the 1% fatality level, then all other smaller hydrogen sulphide release scenarios will not either. All release cases are assessed, however, for the likelihood of contributing to irritation or injury risk levels at the nearest site boundary.

Hydrogen Sulphide Release Cases Modelled

The following cases involving hydrogen sulphide releases were modelled:

1. Catastrophic vessel failures (eg sulphide precipitation vessel and hydrogen sulphide reactor failures). Toxic load and maximum concentrations at the nearest site boundary are calculated. Also, the amount of hydrogen sulphide as a flammable cloud is determined to review the likelihood of a flash fire or vapour cloud explosion.

2. Piping and vessels failures corresponding to the various hole sizes discussed in Section 4, “Release Sources”. Again, toxic load and maximum concentrations at the nearest site boundary are calculated as well as the amount of hydrogen sulphide as a flammable cloud is determined to review the likelihood of a flash fire or vapour cloud explosion.

3. Release from the plant flare system (eg the flare trip fails to shutdown the hydrogen sulphide plant on a flare fault and normal plant vent streams are vented to atmosphere)

The scenario calculated to release the largest inventory of hydrogen sulphide is a pipe fracture (80 mm diameter) where there are two open pipes releasing material to atmosphere plus full plant rate for 1 minute. Practically, all the hydrogen sulphide in the system is released plus plant rate for 1 minute. This is equivalent to 5.97 kg/s for 1 minute. Note that catastrophic vessel failures are likely to stop the hydrogen sulphide production immediately due to damage to fail safe trip components, hence only the inventory of hydrogen sulphide in the system is released.

The toxic load equivalent to 1% fatality is calculated from the probit equation to be 2.8E+06. For the 80 mm pipe fracture failure case (ie the largest release inventory), the calculated toxic load at the nearest site boundary is 1.6E+06 (ie less than that estimated to have a probability of 1% fatality).

As the largest release scenario results in negligible off-site individual fatality risk any smaller release cases will have less impact at the nearest site boundary. Therefore, hydrogen sulphide releases result in very low fatality risk levels at the site boundary and are not considered further.

However, the maximum concentration at the site boundary (876 ppm) does exceed the irritation and injury levels though and, therefore this scenario will have a contribution to irritation and injury risk. It is noted that the duration for the cloud to pass the nearest site boundary is approximately 7 minutes. Given the times for effects to occur in Table 10, this small duration will minimise the likelihood of irritation or injury.

The values of hydrogen sulphide concentration selected for irritation and injury risk levels are taken as 150 ppm and 300 ppm. Given the exposure durations quoted in Table 10 (Ref 5) for these concentration levels (ie 3 to 4 hours and 1 hour, respectively), and the short duration of the cloud to pass a particular location at the nearest site boundary (approximately 7 minutes), these values are considered conservative choices when compared against the DUAP definition of injury and irritation risk which specify levels causing effects over a relatively “short duration”. The failure cases modelled (at various weather/wind combinations) that exceed these levels are shown in Table 11.

Table 11 - Hydrogen Sulphide Release Cases Causing Irritation and/or Injury at the Nearest Site Boundary

Release Case (for specified weather/wind combinations)	Peak Hydrogen Sulphide Concentration at the Nearest Site Boundary (ppm)
80 mm pipe fracture:	
F2 conditions	876
E2 conditions	326
D2 conditions	151
Catastrophic failure of a sulphide precipitation vessel:	
F2 conditions	772
E2 conditions	287
Catastrophic failure of the hydrogen sulphide reactor:	
F2 conditions	619
E2 conditions	231
50 mm hole in a vessel or pipe (F2 conditions)	364

All other failure cases analysed (ie hole sizes 25 mm and less) do not cause hydrogen sulphide levels at the nearest site boundary to exceed the irritation level and hence are not further analysed in this PHA. Also, for the more unstable weather/wind combinations than those shown, the nearest boundary levels of hydrogen sulphide are predicted to be below the irritation level.

The cases shown in Table 11 form the basis for the contribution of hydrogen sulphide releases to irritation and injury risk. This is analysed further in Section 6 of this PHA.

For the largest hydrogen sulphide release case (fracture of a 80 mm diameter pipe), a check was performed to determined the amount of released hydrogen sulphide that was in the flammable region. This cloud, if ignited, could form a flash fire or a vapour cloud explosion. It was calculated that 148 kg of hydrogen sulphide is in the flammable region. This flammable region extends to approximately 100 m from the point of release (ie well inside the nearest boundary). For explosive clouds of less than 1 tonne of material, the probability of ignition leading to either a flash fire or vapour cloud explosion is low (typically less than 1% - Ref 12). As such, the risk of a hydrogen sulphide vapour cloud explosion or flash fire causing off-site effects is negligible.

Other hydrogen sulphide release scenarios modelled involve releases from the flare system. Two runs were performed:

1. The plant is operating at maximum rates and the flare suffers a fault **without** the trip system shutting down the hydrogen sulphide plant (ie the normal vent

gas streams are not combusted but just vented to atmosphere out the top of the flare – 80 m high)

2. The flare header pipe (100 mm diameter) fractures with maximum plant rate vent streams released at pipe rack height (approximately 5 m).

The simulation results for both these cases show that the concentration of hydrogen sulphide at ground level falls below the irritation level at 218 and 231 m, respectively, from the point of release. As these effect distances are well within the nearest site boundary, these two cases do not contribute to off-site irritation (or worse) effects.

4.1.2 Sulphur Dioxide Releases

Sulphuric acid will be produced in a conventional style, sulphur burning acid plant. After the burner, the sulphur dioxide is reacted over a fixed bed catalyst system to form sulphur trioxide. The sulphur trioxide is absorbed in acid to form the required 98 wt% sulphuric acid. Overhead gases from the absorber are vented to atmosphere.

These types of plants run at low pressure (typically 24 kPag after the burner) and hence there exists a low driving force for releases. Gas stream temperatures of 80^{o}C or higher are normal.

Sulphur trioxide is present in the process from the reactor to the absorption tower. Any releases from these areas (including failure of absorption reflux flow) will immediately form white clouds as the sulphur trioxide readily forms sulphuric acid when combined with atmospheric moisture. The sulphuric acid mist generated becomes a dense cloud which partly rains out on to the ground and other surfaces.

This strong affinity of sulphur trioxide with water makes accurate modelling of sulphur trioxide clouds difficult, particularly over large distances such as that to the nearest site boundary. The approach taken in this analysis is to model releases of sulphur dioxide to determine the significant effects, if any, at the nearest site boundary. Depending on these results, off-site effects of sulphur trioxide releases can be surmised. Whilst sulphur dioxide also reacts with atmospheric moisture, the reaction is not as fast as that of sulphur trioxide and is not taken into account in the modelling of releases.

The composition of the sulphur dioxide stream varies from plant to plant (depending on the sulphur dioxide sources), and, of course, within each plant. In this study, a composition of 18 vol% sulphur dioxide in air is used (typical maximum value).

Release scenarios were only performed for the cases where the plant was kept operating. Once the plant is stopped, the low pressure in the equipment minimises the flowrate of further releases.

Release conditions are summarised as follows:

Plant rate (gas stream after burner)	37.3 kg/s
Pressure	24 kPag
Temperature (approximate)	80^oC
Release height (approximate pipe rack level)	5 m

Given this temperature, the density of the sulphur dioxide stream when it is released to atmospheric pressure is calculated to be 1.22 kg/m^3. As this is approximately the same as air at 15^oC (1.23 kg/m^3), the plume is treated as having neutral buoyancy and it is modelled by using the Gaussian neutral gas dispersion correlations (Ref 10). The simulations involving large releases are based on a release duration of one minute (at full plant rate). Large releases will become known (visual, noise and smell as well as process monitoring alarms and trips) soon after the catastrophic failure, hence it is realistic to assume shutdown within one minute. For the smaller releases (from 50 mm holes or smaller), release durations of 15 minutes are modelled (to determine the worst case effect distances). This time allows for operator intervention to manually control and/or stop the leak.

Toxic Impact of Sulphur Dioxide on Humans

The toxicity effects of sulphur dioxide (Ref 13) on humans are summarised in Table 12.

Table 12 - Effects of Sulphur Dioxide on Humans

Exposure Level (ppm)	**Duration (mins)**	**Effects**
1	Immediate	Odour threshold
3 6 – 12	60 Not stated	ERPG 2 level (see Attachment 4) Irritation of nose and throat
54 30 15	1 10 60	Potential for injury Potential for injury ERPG 3 level (see Attachment 4)
100	30	Serious danger
5784	30	LC_{50} (Ref 5)

As discussed previously, toxicity effects resulting in fatality may be estimated using probit equations. For this PHA, the probit equation below (taken from the SHE Pacific HAZAN Course Notes, Ref 12) for sulphur dioxide has been used. Of the probits analysed, it is regarded as the most conservative (ie it should over predict the likelihood of fatality – see Attachment 4 for details relating to sulphur dioxide toxicity and the use of probit equations to predict toxicity effects on humans).

$$Pr = -23.7 + 1.14 \ln (C^{3.7}T)$$

Where C = concentration (ppm)

T = exposure duration (minutes)

The absolute values given in Table 12 form the basis for estimating the likelihood of exceeding irritation or injury risk criteria. The probit equation above provides the probability of fatality for a given toxic load (ie used for estimating individual fatality risk).

Toxic load for sulphur dioxide is calculated within Effects by integrating the concentration at a particular location over the exposure duration. The concentration may vary over time depending on the type and duration of the release. The duration is the lesser of the time taken for the cloud to pass or the maximum exposure time (set to 1 hour in this study). The calculated toxic load is then used in the probit equation to estimate the probability of fatality at a particular location.

The approach adopted in this PHA is to calculate the toxic load at the nearest site boundary to determine if it exceeds the 1% fatality level for a number of significant release scenarios. Any scenarios not exceeding the 1% fatality level will be excluded from the individual fatality risk analysis. All release cases are assessed, however, for the likelihood of contributing to irritation or injury risk levels at the nearest site boundary.

Sulphur Dioxide Release Cases Modelled

The following cases involving sulphur dioxide releases were modelled:

1. Catastrophic vessel failures or full pipe fractures. The release rate is modelled as full plant rate for one minute. Toxic load and maximum concentrations at the nearest site boundary are calculated.

2. Piping and vessels failures corresponding to the various hole sizes discussed in Section 4, “Release Sources”. The effect distance to 4 ppm sulphur dioxide (corrected ERPG 2 level for a 20 minute exposure duration – calculated off-site exposure duration) is calculated to determine the release cases, if any, that contribute to irritation or injury risk at the nearest site boundary.

All simulations take into account that sulphur dioxide is diluted (18 vol%) in air prior to release. As the cloud contains both air and sulphur dioxide, the predicted concentrations and toxic loads for each simulation are corrected to 18 vol% sulphur dioxide for accuracy in predicting the sulphur dioxide levels.

The toxic load equivalent to 1% fatality is calculated from the probit equation to be 1.41E+10 for pure sulphur dioxide (this is corrected in the simulations to take into account that sulphur is 18 vol% on release). For the worst case release of full plant rate for one minute at F2 conditions (ie the largest release inventory), the calculated toxic load at the nearest site boundary is 2.0E+11. Using the probit, this is estimated to have a probability of 83% fatality. At all other weather/wind combinations, the estimated toxic load at the site boundary is less than the 1% fatality level and are deemed negligible fatality risk contributors.

As such, off-site individual fatality risk exists for the worst case release scenario modelled at F2 conditions only and this is further analysed in Section 6 of this PHA.

For all weather/wind combinations for this worst case release scenario, the maximum concentration of sulphur dioxide at the site boundary exceeds the irritation and injury levels stated in Table 12. Hence, this scenario will have a contribution to irritation and injury risk at the nearest boundary for all weather/wind combinations. It is noted that the duration for the cloud to pass the nearest site boundary is approximately 8 minutes. This small duration will help to mitigate the likelihood of irritation or injury.

The values of sulphur dioxide concentration selected for irritation and injury risk levels are taken as 4 ppm and 20 ppm. Given the ERPG (the US Emergency Response Planning Guidelines) values for an exposure duration of 1 hour quoted in Table 12, calculations were performed to determine these irritation and injury concentrations for a 20 minute exposure (ie toxic load was assumed to be constant). The failure cases modelled (at various weather/wind combinations) that exceed these levels are shown in Table 13.

Table 13 – Sulphur Dioxide Release Cases Causing Irritation and/or Injury at the Nearest Site Boundary

Release Case	**Peak Sulphur Dioxide Concentration at the Nearest Site Boundary (ppm)**
Catastrophic vessel failure or pipe fracture:	
F2 conditions	1010
E2 conditions	377
D2 conditions	175
D5.4 conditions	141
C5.4 conditions	63
B3.4 conditions	33
50 mm hole in a vessel or pipe:	
F2 conditions	25
E2 conditions	9
25 mm hole in a vessel:	
F2 conditions	5

All other failure cases analysed (ie hole sizes less than 25 mm) do not cause sulphur dioxide levels at the nearest site boundary to exceed the irritation level and hence are not further analysed in this PHA. Also, for the more unstable weather/wind combinations than those shown, the concentrations of sulphur dioxide at the nearest boundary are predicted to be below the irritation level.

The cases shown in Table 13 form the basis for the contribution of sulphur dioxide releases to irritation and injury risk. This is investigated in Section 6 of this PHA.

With regard to sulphur trioxide releases, it was discussed previously that sulphur trioxide reacts readily with atmospheric moisture to form sulphuric acid which, being a dense mist, rains out significantly on to the ground and nearby structures (Ref 5). Given that sulphur dioxide releases from 50 mm holes (or less) only just cause minor affects at the nearest site boundary, it can be surmised that sulphur trioxide releases from these size holes are unlikely to have any significant off-site impacts (even though the effect concentrations of sulphur trioxide are slightly lower than sulphur dioxide). However, for a worst case release at full plant rates involving the sulphur trioxide steam, off-site effects can certainly be expected. This is included in the risk analysis in Section 6 of this report.

4.2 Fires

Another potential significant hazard associated with the Project is fire. The types of potential fires are torch or jet fires, flash fires and pool fires, depending on the material involved and time of ignition after the release.

The consequences of various levels of thermal radiation emitted from fires are shown in Table 14 (Ref 1). It can be seen that as the incident heat flux increases, the escape potential decreases, since burn injuries would result at the higher heat fluxes for shorter exposures.

Table 14 - Effects of Fire Radiation

Heat Flux (kW/m^2)	Effect
1.2	Received from the sun at noon in summer
2.1	Minimum to cause pain after 1 minute
4.7	Will cause pain in 15-30 seconds and second degree burns after 30 seconds
12.6	30% chance of fatality for continuous exposure. High chance of injury Wood can be ignited by a naked flame after long exposure
23	100% chance of fatality for continuous exposure to people and 10% chance of fatality for instantaneous exposure Spontaneous ignition of wood after long exposure Unprotected steel will reach thermal stress temperatures to cause failure
35	25% chance of fatality if people are exposed instantaneously
60	100% chance of fatality for instantaneous exposure

The approach adopted in this PHA is to analyse each identified significant fire incident to determine if there are off-site effects likely to cause fatality or injury. Depending on these results, less significant fire incidents may require further analysis. As per the DUAP heat injury criterion (Ref 1), incident heat flux radiation at residential areas should not exceed 4.7 kW/m^2 at frequencies of more than 50 chances in a million per year. Given the large distances to the site boundaries, this is the main heat flux value of interest from the analysis.

4.2.1 Torch or Jet Fires

Jet fires occur when a flammable liquid or gas, under some degree of pressure, is ignited after release, resulting in a long stable flame. The rate of material release is initially calculated. Given this rate, the amount of heat flux generated at the source of the fire is then calculated. Established correlations are then used to determine the distances to the selected levels of heat radiation. See Attachment 2 for details of the heat flux calculations used in Effects.

From the identified hazardous incidents in Section 3.3, the significant torch fires events are shown in Table 15 (along with the respective release conditions). The release rates are calculated within Effects for full pipe fracture scenarios. For hydrogen and hydrogen sulphide, the release rates will be restricted by production rates after the initial high rates associated with depressurisation reduce. For natural gas releases (in the high pressure supply main on site), the gas will choke due to the resistance effect of such a long pipe. This choke flow is given in Table 15.

Note that the calculated release rates correspond to the flow out of a single pipe. For pipe fracture cases, flow can be the summation of the rates from two pipes (ie there are two release points) if there are significant quantities of material supplying the two break points. For the scenarios modelled in this PHA, the release rates are taken as those from one pipe only due to the low inventory of gas downstream of the breaks.

Table 15 – Torch Fire Scenarios

Release Scenario:	**Pres, barg**	**Temp, °C**	**Pipe Size, mm DN**	**Release Rate, kg/s**	**Production Rate, kg/s**
Hydrogen (supply line to H_2S plant)	9	40	80	0.89	0.045
Hydrogen (approximate reformer conditions – synthesis gas)	20	50	50	0.57	0.045
Hydrogen sulphide (largest line at sulphide precipitation vessels)	9	60	100	8.37	0.72
High pressure natural gas supply main	34.5	25	150	7.6	-
Low pressure natural gas – site supply	10	25	150	12.6	-

The scenarios shown in Table 15 were modelled within Effects to determine the effect distances to specified levels of heat radiation. All runs are based on vertical releases (some horizontal cases were modelled separately but were found to have lower effect distances for the specified radiant heat levels). The effect distances to a radiant heat level of 4.7 kW/m^2 for the stated scenarios in Table 15 are shown in Table 16.

In the calculation of the effect distances shown in Table 16, no allowance has been taken for release rate being limited by plant rate. This is a conservative approach. Also, a wind speed of 5.4 m/s is used in the simulations to include the effects of flame tilt (maximises effect distances).

Table 16 - Torch Fire Scenarios Effect Distances

Release Scenario:	**Distance from a vertical torch fire to a radiant heat level of 4.7 kW/m^2, (m)**
Hydrogen (supply line to H_2S plant)	7
Hydrogen (approximate reformer conditions – synthesis gas)	< 2
Hydrogen sulphide (largest line at sulphide precipitation vessels)	< 5
High pressure natural gas supply main	21
Low pressure natural gas – site supply	27

As can be seen by these effect distances, there is negligible impact of the significant torch fire scenarios at the nearest site boundary (over 1 kilometre away). Therefore, no off-site injury or fatality risk can be expected from torch fires and they are not included in any further off-site analysis in this PHA. This risk of knock-on or propagation style incidents, initiated by torch fires, will be discussed later.

Another hydrogen release scenario (the atmospheric vent from the hydrogen plant) was modelled to determine the extent of the flammable region at full plant rates. The outer boundaries of the flammable cloud are defined by the lower explosive limit (LEL), which is 4 vol% for hydrogen. Release conditions are assumed as follows:

Release height	36 metres
Diameter of pipe	150 mm
Gas exit velocity	30 m/s
Atmospheric conditions	F2
Roughness length (plant environment)	3 m
Vertical orientation of pipe	

The Ooms plume path dispersion model was used to disperse the plume. It was shown that the flammable region does not extend beyond 5 m from the point of release, therefore ignition of the cloud is extremely unlikely. Given the low molecular weight of hydrogen, hence good dispersion properties, this is not unexpected.

If the vent stream were to be ignited (eg lightning), it was calculated that radiant heat levels of 4.7 kW/m^2 would extend to 7 m from the point of release. Therefore, given this small distance, the risk of injury or propagation style incidents from ignition of the hydrogen vent stream is negligible.

4.2.2 Flash Fires

A flash fire can occur when a cloud of flammable gas, mixed with air, ignites. If the conditions allow, it is possible for the flame to accelerate to a sufficiently high velocity for a vapour cloud explosion to occur.

Though very brief, a flash fire can seriously injure or kill anyone in the burning cloud. Its effects are confined almost entirely to the area covered by the cloud. Incident propagation can occur through ignition of materials or structures within the cloud.

Historically (Ref 12), about one in ten releases of gas or vapour result in delayed ignition. The rest are not ignited and disperse safely, or are ignited immediately. About one in ten of the delayed ignitions result in a vapour cloud explosion, the rest being flash fires. There are no accurate ways to determine the likelihood of an explosion or flash fire occurring from a delayed ignition for a given flammable cloud.

In this PHA, the approach taken is to model the consequences of the significant flammable gas or vapour releases as both flash fires and vapour cloud explosions to determine the effects at the nearest site boundary (prior to evaluating risk which takes into account the probability of each hazardous event occurring). If the effects at the nearest site boundary are shown to be negligible, then their contribution to risk is also negligible.

The significant hazardous events identified in Section 3.3 that could lead to the largest flash fires are the same events as those identified for the significant torch fire scenarios.

A reasonable working assumption for evaluating the effects of flash fires is to calculate the radius of the flame as the radius of a 70 kPa overpressure (ie if the cloud had exploded) and then to assume a probability of 100% within that radius and zero outside (Ref 12). This is a reasonable working assumption given that flash fires are for brief durations and serious injury will not occur unless the person is within or very close to the flame.

For each release scenario, a 10 minute duration is selected. As the plant users of hydrogen, hydrogen sulphide and natural gas cannot operate without any gas supply, as soon as the pipe fractures occur (largest release cases) the operators will be alerted by instrumentation monitoring and/or gas detection (other than noise, smell etc). The 10 minute duration is selected to allow operators time to initiate manual isolation of the respective lines.

Given the rates determined in Section 4.2.1 for pipe fractures and a 10 minute duration time, the total amount released can be calculated. No allowance is made for dispersion of some of the released material to below the lower explosive limit (ie conservative). The TNT model (Ref 12) was used to calculate the distance to the

70 kPa overpressure (explosion efficiency factor of 0.04 used). The results of this analysis are shown in Table 17.

Table 17 - Effect Distance for Significant Flash Fire Events

Release Scenario:	**Release Rate (1), kg/s**	**Cloud Mass, kg**	**Equivalent TNT, kg**	**Equivalent Flash Fire Effect Distance, m**
Hydrogen (supply line to H_2S plant)	0.89	530	650	35
Hydrogen (approximate reformer conditions – synthesis gas)	0.57	340	420	30
Hydrogen sulphide (largest line at sulphide precipitation vessels)	8.37	5 020	790	37
High pressure natural gas supply main	7.6	4 560	1 980	50
Low pressure natural gas – site supply	12.6	7 560	3 290	59

Notes 1. Release rates are initial, instantaneous rates (which decay over time due to lower production rates and limited system hold-up). Therefore, these calculations are conservative.

As the results in Table 17 show, the equivalent flash fire effect distance (100% fatality) for the significant pipe fracture cases over a 10 minute duration (conservative for operating plant incidents due to proposed protective features, ie tripping of the hydrogen sulphide plant, for example, can be expected within one minute) are all less than 100 m from the point of ignition. Whilst cloud drift may occur in some circumstances, the likelihood of these clouds travelling off-site prior to ignition is low (given the sources of ignition on the site as well as the effects of dispersion over distances of 1 kilometre or more).

As such, the risk of fatality or injury from flash fires at the nearest site boundary is negligible.

4.2.3 Pool Fires

Pool fires occur if a flammable or combustible liquid accumulates in a pool on the ground and vapours caused by evaporation are subsequently ignited. The resultant fire covers the whole pool area.

The thermal radiation from pool fires tends to attenuate rapidly with distance from the flame surface and so thermal effects are relatively localised. Hence for this PHA, off-site effects from pool fires are expected to be negligible. However, the risk of escalation to other incidents (from pool fires) should also be reviewed.

The hazardous events identified in Section 3.3 that could lead to the significant pool fires are:

1. Loss of containment of diluent either in the solvent extraction or storage tank areas (5 tonne inventory)

2. Loss of containment of diesel at the ore processing plant tank farm, the rail siding, the mining contractors area or the limestone quarry (a maximum 50 000 L tank size was assumed at each location)

In the analysis of pool fires, loss of containment is assumed to have occurred from one tank only. Bund walls are assumed to be either 1.1 m high with total containment being 110% of tank capacity, or the height of the diesel tank with a double wall containment design (ie at the mine site process plant area). These assumptions define the area of the contained pool. Note that the pool area is assumed to be square for tanks with 1.1 m high bund walls.

For the solvent extraction area, the floor area (750 m^2) was determined from the proposed plant layout. Whilst a loss of containment of diluent may not cover this area entirely (inventory limited and no allowance for footings etc), the total area is included in the analysis.

The effect distances to selected radiant heat levels were calculated within Effects (see Attachment 2) for the given material and calculated pool area. The percentage of heat radiated from the fire is 35% (this is the default value within Effects, conservative for most chemicals involved in large pool fires due to smoke restricting the amount of radiated heat). The results are shown in Table 18.

Table 18 - Effect Distances for Significant Pool Fires

Pool Fire Scenario:	**Pool Area, m^2**	**Equivalent Pool Radius, m**	**Distance to the Selected Radiant Heat Level from the Centre of the Fire, m**		
			23 kW/m^2	**12.6 kW/m^2**	**4.7 kW/m^2**
Loss of containment of diluent at the storage tank (5 te)	6.8	1.4	2.5	4.5	9
Loss of containment of diluent at the solvent extraction area (area = 750 m^2 approx.)	750	15	25	30	55
Loss of containment of diesel from a 50 000 L tank (worst case modelled, ie a pool fire for one of the tanks surrounded by a 1.1 m high bund wall)	50	4.0	7	10	19

As expected, the distances to the radiant heat levels likely to cause injury or fatality from the significant pool fire scenarios are less than that to the nearest site boundaries. As such, off-site injury or fatality risk due to pool fires can be neglected.

The risk of propagation style incidents due to thermal effects is discussed in Section 6 of this PHA.

4.2.4 Warehouse Fires

There will be a dangerous goods warehouse on the site to store the required packaged chemicals (relatively small volumes – see Attachment 1). The warehouse will be designed to the appropriate standards (eg AS/NZS 3833, The Storage and Handling of Mixed Classes of Dangerous Goods in Packages and Intermediate Bulk Containers). This will include the segregation of non-compatible classes of dangerous goods.

Designing to standards such as AS/NZS 3833 ensure that the risk of unwanted events (eg fires) is low. Given the high integrity design requirements of the standards with the volumes of small packaged goods stored in the warehouse, it is very unlikely that a warehouse fire will have any significant off-site impacts (ie at a distance in excess of 1 kilometre). Therefore, it is considered that a warehouse fire poses negligible off-site risk.

4.3 Explosions

As discussed in Section 4.2.2, a vapour cloud explosion can occur when a cloud of flammable gas, mixed with air, ignites. Overpressures generated from the explosion have the potential to damage plant and equipment, and/or injury or kill people.

The consequences of various levels of overpressure generated from vapour cloud explosions are shown in Table 19 (Ref 1).

Table 19 - Effects of Explosion Overpressures

Overpressure kPa	Effect
3.5	90% glass breakage No fatality and very low probability of injury
7	Damage to internal partitions and joinery but can be repaired Probability of injury is 10%. No fatality
14	Houses uninhabitable and badly cracked
21	Reinforced structures distort Storage tanks fail 20% chance of fatality to a person in a building
35	Houses uninhabitable Trucks and plant items overturned Threshold of eardrum damage 50% chance of fatality for a person in a building and 15% chance of fatality for a person in the open
70	Threshold of lung damage 100% chance of fatality for a person in a building or in the open Complete demolition of houses

In this PHA, the approach taken is to model the consequences of the significant flammable gas or vapour releases as vapour cloud explosions to determine the effects at the nearest site boundary (prior to evaluating risk which takes into account the probability of each hazardous event occurring). If the effects at the nearest site boundary are shown to be negligible, then they have a negligible contribution to risk.

The significant hazardous events identified in Section 3.3 that could lead to the largest vapour cloud explosions are the same events as those identified for the significant torch fire scenarios and flash fires. As per the analysis for flash fires, a release scenario of 10 minutes duration is selected (hence the same amounts of flammable gas or vapours in the cloud are predicted). Again, no allowance is made for dispersion of some of the released material to below the lower explosive limit (ie conservative).

The TNT model (Ref 12) was used to calculate the overpressures at the nearest site boundary (1 050 m) for potential significant flammable gas or vapour clouds that could form (see Table 17). The results of this analysis show that the predicted explosions overpressures at the nearest site are less than 1 kPa for all significant scenarios.

Given the overpressures and corresponding effects shown in Table 19, the risk of fatality or injury from vapour cloud explosions at the nearest site boundary is deemed to be negligible. Also, at these levels of overpressure (less than 1.4 kPa), missile effects are deemed to be negligible (Ref 12).

A number of other explosive hazardous events were identified and shown in Section 3.3. These were (including the main means of mitigation):

1. Hydrogen explosions within sulphuric acid storage tanks (the tanks will be continuously vented to prevent this)

2. Hydrogen sulphide explosions in storage tanks (these tanks are padded or purged with nitrogen to prevent explosions)

3. Hydrogen sulphide trapped under the building roof (roof to be vented and gas detectors provide warning of a release)

4. Explosion in the electrowinning tankhouse (hydrogen concentration from the cells is approximately 0.1% - less than LEL, fans are used in the tankhouse to disperse the gas)

5. An explosion involving the condenser-reboiler in the air separation unit (impurities such as hydrocarbons are removed in guard beds at the inlet to the plant, bleed stream(s) from the reboiler zone assist in purging any hydrocarbon slip)

6. Internal explosion in the hydrogen plant reformer (a robust burner management system is to be used – purging sequences included, operator training)

7. Internal explosions in the hydrogen plant if air is drawn in during shutdowns (padding of catalyst with nitrogen as well as operator training)

8. Explosions within the hydrogen sulphide reactor (instrumentation and controls, operator training)

9. Explosions within sulphur burner (or downstream equipment) in the sulphuric acid plant (robust burner management system used including trips)

The likelihood of these events occurring is low due to the proposed protective features. Importantly, these explosions are confined. Accurate modelling of confined explosions is difficult to achieve as “the degree of confinement” and explosion dynamics used to determine the overpressures are difficult to estimate. Given that these events mostly involve relatively small volumes, confined gas phase explosions and, historically, these types of incidents have shown that much of the explosion energy is absorbed by destruction of the vessel, tank confining the explosion then the effects at distances over 1 kilometre are considered to be minor (as per the larger vapour cloud releases).

5 FREQUENCY ANALYSIS

The frequency of an event is defined as the number of occurrences of the event over a specified time period; with the period in risk analysis generally being taken as one year.

Two approaches have been used to estimate the frequencies of hazardous events. The first method is to use statistical data relating to failure of whole systems or equipment items. Secondly, for the catastrophic release scenario from the sulphuric acid plant, a typical historical failure rate for major off-site effects based on the UK HSE (Health and Safety Executive Advisory Committee) (Ref 12) acceptability criteria is used.

5.1 Generic Equipment Failure Frequencies

For piping and equipment failures, statistical frequencies have been estimated from data compiled and published for internal use by Orica (Ref 14) or from frequency estimates published by the Institution of Chemical Engineers (Ref 15).

Table 20 - Generic Equipment Failure Frequencies

Type of Failure	**Failure Rate (x 10^6 per year)**
Pipelines	
3 mm hole	9 / m (ie per metre of pipe)
13 mm hole	3 / m
50 mm hole	0.3 / m
3 mm gasket (13 mm hole equivalent)	5 / joint
Guillotine fracture (full bore):	
< 50 mm	0.6 / m
50 mm but < 100 mm	0.3 / m
> 100 mm	0.1 m
Vessels	
6 mm hole	24
13 mm hole	6
25 mm hole	3
50 mm hole	3
Catastrophic failure – pressure vessel	1

The frequencies in Table 20 form the basis for estimating the risk of irritation and injury from hydrogen sulphide and sulphur dioxide releases. This is further analysed in Section 6.

5.2 Sulphuric Acid Plant Significant Gas Release Frequency

Significant gas releases from the sulphuric acid plant are those from catastrophic vessel failures or pipe fractures where large volumes of sulphur dioxide or sulphur trioxide are released over a 1 minute duration (see Section 4.1.2).

Details of the sulphuric acid plant design (eg pipe lengths, vessel sizes etc) would not become available until the detailed design stage of the Project and, as such, this PHA is based on generic sulphuric acid plant designs. Hence, rigorous equipment failure analysis is not possible. However, the approach used in this PHA is to treat the sulphuric acid plant as a unit and, based on historical and acceptable criteria, estimate a major release frequency.

The UK HSE (Ref 12) states:

"*If assessments indicated with reasonable confidence that in a particular plant a serious accident was unlikely to occur more often than once in 10 000 years… this might perhaps be regarded as just on the borderline of acceptability, bearing in mind the known background of risk faced every day by the general public."*

With the level of technical risk mitigation features used in chemical plant design and construction now, this major accident frequency is considered to be obtainable (whereas several decades ago the frequency was closer to one every 1 000 years – Ref 12).

A simplistic assessment for the frequency of serious releases from the sulphuric acid plant follows. This is compared to the target value as set by the HSE.

By multiplying an anticipated number of process vessels (approximately 6 to 8) and a minimum length of pipe (all > 100 mm diameter) handling gas within the sulphuric acid plant (say, 500 m), with the frequencies quoted in Table 20 for failures, a frequency of serious releases of sulphur dioxide or sulphur trioxide can be approximated. That is,

(8 vessels x 1.0xE-06) plus (500 m of pipe x 0.1xE-06) gives 58xE-06/year.

This is less than the target figure of 1.0xE-04/year.

Even though this is a simplistic estimate for the frequency of the major releases of sulphur dioxide and sulphur trioxide from the sulphuric acid plant, it confirms the HSE target value as being of approximately the right order of magnitude. Therefore, the frequency of serious sulphur dioxide / sulphur trioxide releases is taken to be one incident every 10 000 years.

6 RISK ASSESSMENT AND CONCLUSIONS

6.1 Methodology

Risk from the proposed ore processing plant, limestone quarry, rail siding and gas pipeline has been estimated by qualitative and/or quantitative analysis of events likely to have an off-site impact. As shown in Section 4 of this PHA, most events have negligible impact at the respective site boundaries (and hence negligible risk).

The risk assessment has three major forms:

- **Individual Fatality Risk** – The likelihood (or frequency) of fatality to notional individuals at locations around the site boundary, as a result of the postulated toxic gas releases, fire and explosions. Given that only one event (sulphur oxides release from the sulphuric acid plant) could be serious enough to cause fatality at the site boundary, then the corresponding risk is calculated manually (see Section 6.2). The units for individual risk are probability (of fatality) per million per year. By convention it is assumed that people are located outdoors, are always present and take no evasive action if an incident occurs. This is a very conservative assumption, particularly for a sparsely populated rural location when people are not likely to be at the site boundary for a large percentage of the time. Also, for toxic gas releases, people are in fact very likely to be able to escape or take evasive action.

- **Injury and Irritation Risk** – This is the result of injury or irritation to individuals at locations around the site boundary as a result of the same scenarios used in the assessment of individual fatality risk. As for individual risk, the surrounding sparsely populated rural area and evasive action is not allowed for.

- **Societal Risk** – This takes into account the number of people exposed to risk. Whereas individual risk is concerned with the risk of fatality to a (notional) person at a particular location (person ‘most at risk’, ie outdoors), societal risk considers the likelihood of actual fatalities among people exposed to the hazard.

To calculate these risk types the following information is used:

- The probability of fatality for all incidents at the nearest site boundary (Section 4)
- The events whose consequences exceed a defined injury or irritation target at the nearest site boundary (Section 4)
- The frequency of each event (Section 5)
- Wind / weather data (Attachment 3)
- Population data for the surrounding area

The target risk criteria (as published by the DUAP) is shown in Table 1.

6.2 Mitigating Features

By convention in Australia, mitigation factors are not taken into account in the estimation of individual fatality risk. An individual is considered to be located permanently at a particular location and no scope for shelter or escape is factored into the calculations. The risk results are essentially the risk at a location, not necessarily to a particular individual.

If an incident occurs, a person in the open may escape inside or move out of the cloud when feeling the effects of toxic gas. As both hydrogen sulphide and sulphur dioxide can be detected by low odour, even at low concentrations, instinctively people can take shelter to avoid the significant effects of the cloud. However, for hydrogen sulphide, loss of smell can occur. Therefore, people can believe that the danger has passed when, in fact, it is still present. For any major hydrogen sulphide releases, it will be the responsibility of the operating company to enact emergency response plans should off-site people be at risk. Note that as per the analysis in Section 4, credible off-site risk due to hydrogen sulphide releases is limited to irritation and injury risk only.

Other risk mitigation features for this particular site include:

- The duration of the toxic gas clouds at the nearest mine site boundary are limited (as determined in Section 4). Cloud durations for the worst case conditions (ie F2 weather conditions) vary from 7 to 20 minutes.

- The surrounding area is characterised by a rural environment with low population density (relative to residential to which the criteria relate). This density is not likely to change with the operation of the mine, as it is anticipated that the majority of workers would settle in existing, distant population centres.

- Whilst there is a road at the nearest mine site boundary, the traffic flow is such that it is not in use 24 hours per day. In any event, if the car occupants were to smell a release from the plant, it is likely that they would continue driving to avoid the plume.

- For the plume modelling in Section 4, no allowance was taken for increased turbulence (and hence shorter effect distances) from the plant and site buildings etc.

However, even given these mitigation features, the potential for a person to escape from a toxic gas release etc has not been included in the present analysis of individual risk of fatality or irritation/injury. The results of the risk assessment are therefore considered highly conservative, particularly for injury or irritation effects.

6.3 Individual Fatality Risk

Of the hazardous events identified for the proposed plant, the only event with credible off-site individual fatality risk is a catastrophic release of sulphur dioxide and sulphur trioxide under F2 weather / wind conditions. As calculated in Section 4, the corresponding probability of fatality from the concentrations experienced at the nearest site boundary was 83%. For the sake of simplicity of assessment (accurate modelling of sulphur trioxide releases is difficult due to its affinity for water), this high probability of fatality is taken for both sulphur dioxide and sulphur trioxide releases.

The frequency of the event is taken as 1.0xE-04/year (Section 5.2).

To calculate the risk, the percentage of the total time that the weather / wind conditions exist which blow towards the nearest mine site boundary are required. A 45^o sector, centred on a line from NE to SW, is chosen (as the Fifield to Wilmatha Road runs SE to NW). Hence, a wind blowing 22.5^o either side of this line in a westerly direction will approximately carry the plume the estimated distance to the nearest site boundary.

From the weather / wind data in Attachment 3, the percentage of time F2 conditions exist in this sector is calculated to be 1.9% (ie NE + 0.5 x (NNE + ENE)).

The corresponding risk of fatality at the nearest mine site boundary is then calculated by multiplying the event frequency by the probability of fatality by the probability of weather / wind conditions to cause the plume to travel to the point of interest, ie,

Individual fatality risk = 1.0xE-04 x 0.83 x 0.019 per year

= 1.6xE-06 per year

Note that no allowance has been made for mitigating features such as likelihood of people being present, low surrounding population density, probability of escape, increased dispersion due to plant structures etc.

This result compares favourably to the risk criteria presented in Table 1. Given the accuracy of models used to predict concentrations of sulphur dioxide over such a large distance as well as the accuracy of the probit used to predict probability of fatality (the more conservative probit was used in the analysis), the calculated result indicates that the off-site individual fatality risk is relatively low. For such a large distance from the plant to the area of interest, this result is not unexpected.

In summary, the risk of off-site individual fatality risk is considered low from the proposed plant.

6.4 Irritation and Injury Risk

The concentrations of the two toxic gases that, if released, could have effects at the nearest mine site boundary, were determined specifically in Section 4.

For hydrogen sulphide:

Irritation level = 150 ppm (for 3 to 4 hours exposure – conservative time)

Injury level = 300 ppm (for 1 hour exposure – conservative time)

and for sulphur dioxide:

Irritation level = 4 ppm (for 20 minutes exposure)

Injury level = 20 ppm (for 20 minutes exposure)

The total (summed) frequency of all events that cause off-site concentrations at the nearest boundary above these levels was calculated to compare to the target values in Table 1. As per the calculation of individual fatality risk, the frequency of occurrence is mitigated (multiplied by) the probability of the appropriate weather / wind conditions. The events that contribute to off-site irritation risk are summarised in Table 21. The frequencies are taken from the data given in Section 5.

Table 21 – Contributors to Off-site Irritation Risk

Event	**Gas Concentration at the Nearest Site Boundary, ppm**	**Event Frequency, per million per year (pmpy)**	**Percentage Probability of Weather / Wind Conditions in SW direction**	**Frequency of Off-site Irritation Risk, pmpy**
Hydrogen Sulphide:				
80 mm pipe fracture:				
F2 conditions	876	48 (Note 1)	1.9	0.9
E2 conditions	326	48 (Note 1)	2.5	1.2
D2 conditions	151	48 (Note 1)	3.8	1.8
Catastrophic failure of a sulphide precipitation vessel:				
F2 conditions	772	1	1.9	0.02
E2 conditions	287	1	2.5	0.02
Catastrophic failure of the hydrogen sulphide reactor:				
F2 conditions	619	1	1.9	0.02
E2 conditions	231	1	2.5	0.02
50 mm hole in a vessel or pipe (F2 only)	364	57 (Note 2)	1.9	1.1
Sulphur Dioxide:				
Catastrophic vessel failure or pipe fracture:				
F2 conditions	1010	100	1.9	1.9
E2 conditions	377	100	2.5	2.5
D2 conditions	175	100	3.8	3.8
D5.4 conditions	141	100	4.1	4.1
C5.4 conditions	63	100	2.4	2.4
B3.4 conditions	33	100	2.6	2.6
50 mm hole in a vessel or pipe:				
F2 conditions	25	174 (Note 3)	1.9	3.3
E2 conditions	9	174 (Note 3)	2.5	4.3
25 mm hole in a vessel:				
F2 conditions	5	24 (Note 4)	1.9	0.45
Total:				30

Notes: 1. 162 metres of pipe at a frequency of 0.3 / m (per million per year)

2. Three vessels (at 3 pmpy each) and 162 metres of pipe (at 0.3 / m pmpy)

3. Eight vessels (at 3 pmpy each) and 500 metres of pipe (at 0.3 / m pmpy)

4. Eight vessels at 3 pmpy each

As can be seen from Table 21, the total frequency of exceeding irritation risk levels for all identified gas releases is 30 pmpy. This value compares favourably with the **residential** target value of 50 pmpy. As such, calculated off-site irritation risk levels are considered low. A similar analysis is performed for injury risk. The events that lead to potential off-site injury are summarised in Table 22.

Table 22 - Contributors to Off-site Injury Risk

Event	**Gas Concentration at the Nearest Site Boundary, ppm**	**Event Frequency, per million per year (pmpy)**	**Percentage Probability of Weather / Wind Conditions in SW direction**	**Frequency of Off-site Irritation Risk, pmpy**
Hydrogen Sulphide:				
80 mm pipe fracture:				
F2 conditions	876	48	1.9	0.9
E2 conditions	326	48	2.5	1.2
Catastrophic failure of a sulphide precipitation vessel:				
F2 conditions	772	1	1.9	0.02
Catastrophic failure of the hydrogen sulphide reactor:				
F2 conditions	619	1	1.9	0.02
50 mm hole in a vessel or pipe (F2 only)	364	57	1.9	1.1
Sulphur Dioxide:				
Catastrophic vessel failure or pipe fracture:				
F2 conditions	1010	100	1.9	1.9
E2 conditions	377	100	2.5	2.5
D2 conditions	175	100	3.8	3.8
D5.4 conditions	141	100	4.1	4.1
C5.4 conditions	63	100	2.4	2.4
B3.4 conditions	33	100	2.6	2.6
50 mm hole in a vessel or pipe:				
F2 conditions	25	174	1.9	3.3
Total:				23

As can be seen from Table 22, the total frequency of exceeding injury risk levels for all identified gas releases is 23 pmpy. Given the rural location and the conservatism in the analysis work, this value also compares favourably with the **residential** target value of 10 pmpy.

From the results shown in Table 22, it can be seen from the individual contributors that the dominant contributor to off-site injury risk is the catastrophic gas release case from the sulphuric acid plant. From a historical perspective, this type of catastrophic release case (ie failure of a vessel or pipe fracture) is rare for these plants.

Again, given the limitations of dispersion modelling over such a large distance, the conservative approach adopted in the analysis (ie no allowance for increased dispersion due to plant structures, conservative selection of event frequencies etc), and the rural location (and hence the low likelihood of people at the site boundary who cannot escape in the event of a gas release), then the risk of off-site injury is considered low.

For the risk of injury from fires and explosions, as per the analysis in Section 4, there is no credible likelihood of exceeding either 4.7 kW/m^2 or 7 kPa at any site boundaries. Therefore, off-site injury risk from fires and explosions is considered negligible.

6.5 Societal Risk

Societal risk results are usually presented as F-N curves which show the frequency of events (F) resulting in N or more fatalities. To determine societal risk, it is necessary to quantify the population within each zone of risk surrounding a facility. By combining the results for different risk levels, a societal risk curve can be produced.

Societal risk is normally calculated where the 1 pmpy contour (or calculated risk level) approaches closely to residential areas or sensitive land uses or when events with very large consequence distances are being assessed. Hence, the potential exists for multiple fatalities as a result of a single accident.

For this particular study, only one incident (catastrophic failure of a vessel or pipe within the sulphuric acid plant) was identified that could cause fatality off-site. Hence, there is only one frequency that could be used in societal risk calculations. Given the rural nature of the land with the sparse locations of the nearby farm houses (see Section 2.1), the calculation of societal risk is not justified, ie the likelihood of multiple fatalities is very low. Given that only one incident was identified for off-site fatality risk then the individual fatality risk calculation in Section 6.3 is the most appropriate for this site. This showed a low level of off-site fatality risk. Hence, no societal risk calculations are warranted or performed.

Societal risk associated with transport generated by the Project would be attributed to the risk of incidents with other road users. Transport safety on the roads anticipated for use during the Project as addressed by others in a separate Transport Report completed for the Project. Relevant details pertaining to proposed road and intersection upgrades, and timing of school bus movements and mine traffic are included within that report all of which serve as mitigating factors for the risk of transport incidents.

6.6 Cumulative Risk

Another form of risk requiring evaluation as per HIPAP 6 (Ref 2) is cumulative risk. This is the summation of calculated levels of risk from all hazardous facilities within a particular area. Given the rural location (ie no nearby hazardous industries) and the calculated low levels of individual fatality risk posed by the facility at the site boundaries, then assessment of cumulative risk is unnecessary for this proposal.

6.7 Incident Propagation or Domino Incidents

A potentially hazardous event within a plant can cause further incidents in the same plant, or in some cases in other plants. The secondary event is sometimes called a knock-on or domino event. With any large site there is potential for a severe incident in one area to cause a knock-on or domino incident in another area. Typically, releases that catch fire or explode have the potential for knock-on events (ie due to thermal radiation, explosion overpressures or, possibly, due to missiles).

As shown in Figure 4, the plant layout includes generous separation distances between most process areas (eg the distance from the hydrogen sulphide plant to the sulphide precipitation area is approximately 30 metres). As determined in Section 4, the likelihood of propagation due to thermal radiation etc is low at these distances.

Another advantage of the generous plant spacing is the reduced risk of transport initiated events (eg trucks colliding with storage tanks). As a means of further mitigation for these types of domino events, hazardous plant areas will be physically protected by containment structures such as bund walls.

A minor risk is propagation due to a torch fire from a pipe release within a pipe rack. Mitigation of this type of event includes designing and maintaining the pipes to recognised international standards, provision of emergency response equipment such as fire hydrants nearby and minimisation of leak points (eg flanges) within the pipe racks. This is, however, no different to any other well designed hazardous chemical plant.

Another minor risk is the likelihood of propagation by events such as earthquakes or aircraft crashes. However, given the proposed site location, both events are of low risk.

Irrespective of the mitigation afforded by the plant layout etc, should a domino incident occur, for most incidents the effects are largely contained on site (as per the analysis in Section 4). Should an event occur due to propagation with off-site effects then, again, the analysis in Section 4 still holds. As shown, there are low off-site levels of individual fatality risk, irritation risk and injury risk. Therefore, propagation (or knock-on or domino) type incidents do not pose any unacceptable levels of risk from the facility.

6.8 Risk to the Biophysical Environment

The main concern for toxic risk to the biophysical environment is generally with effects on whole systems or populations. Whereas any adverse effect on the environment is obviously undesirable, to have an incident with such consequences requires exposure of a sensitive area to either large effect, short term releases or smaller effect, long term releases. For this site, the latter includes seepage from the tailings dam etc and continuous gas emissions (eg sulphur dioxide from the hydrogen sulphide flare). These events are assessed separately within the EIS for the project and are not included here.

Given the limited number of events (large effect, short term releases) that can occur at this site with off-site impacts (due to the large distance to the nearest site boundary) and the rural nature of the surrounding area, the risk to people and other biological groups (animals, plants etc) is low. This has been shown by analysis in this section above.

In summary, whilst off-site effects can be expected if a major release were to occur, there are no identified whole systems or populations which are at unacceptable levels of risk due to the potentially hazardous events reviewed in this PHA.

For completeness, risks to the biophysical environment due to significant loss of containment events are summarised below.

6.8.1 Escape of Materials to Atmosphere

The potential events that could lead to the escape of significant quantities of harmful materials to the atmosphere (and the effects / mitigation features available) are summarised as follows:

1. Dust release from stockpiles (water sprays and dust suppressant to be used)

2. Hydrogen sulphide releases (analysis as per Section 4 of this PHA)

3. Products of combustion from fires (hydrocarbon fires typically generate carbon dioxide and water which readily disperse due to buoyancy of the plume)

4. Sulphur oxide releases (including sulphuric acid mist) from the sulphuric acid plant (generally, containment is within process piping and equipment and startup emissions etc are dispersed via the plant stack) or from sulphur fires (sulphur fires are slow burning, easy to detect and typically smothered to extinguish)

5. Loss of containment of process gases, eg hydrogen, natural gas (if released, these types of gases readily disperse due to their low molecular weights)

6.8.2 Escape of Materials to Soil or Waterways

The potential events that could lead to the escape of significant quantities of harmful materials to the soil or waterways (and the effects / mitigation features available) are summarised as follows:

1. Loss of containment of acid, acidic ore solution or other hazardous liquid within the process or storage areas (all areas bunded to contain spills, disposal of spills on a as needs basis)

2. Loss of containment of hazardous liquids outside of bunded areas (site stormwater and effluent systems route all flows to the treatment plant area, thereby minimising the chance of harmful soil or waterways effects)

3. Rupture of tailings pipe (high integrity pipe design, instrumentation used to monitor flow problems)

4. Loss of containment from tailings dam, surge dam or evaporation pond (conformance to dam safety regulations including routine monitoring of dam's structural condition)

Further detail of mitigation measures and discussion of the potential environmental impacts relating to loss of containment events is provided in the main text of the EIS.

6.9 Risk Reduction Measures

As can be seen from the analysis of off-site individual fatality risk, and irritation and injury risk, the dominant contributor to risk is a major gas release from the sulphuric acid plant. All other scenarios that have an effect at the nearest site boundary are minor contributors to risk only.

The design approach for all plants (ie the main ore processing plant as well as the ancillary plants, eg the sulphuric acid plant) is to use internationally recognised design and construction companies who follow the appropriate standards and codes. This is evident already as some of the main companies are being approached for proposals on "build, own and operate" plants (ie a recognised industrial gas company will, mostly likely, design, install and operate the air separation unit). As such, 'state-of-the-art' plant and equipment is intended to be installed and then operated by industry leaders.

To complement this approach to plant design, it is proposed to buy a safety management system from a recognised leader in the field and customise this for implementation at the site.

This approach to design and the use of safety management systems is difficult to quantify in terms of the risk reduction effect. No allowance for this approach has been included in the analysis within this PHA. However, the approach is consistent with current 'best practice' within industry and will serve to mitigate the risk of the identified hazardous events within this analysis.

Therefore, no further safety measures are recommended at this stage. Should the project proceed, then the details of the plant design and operation should be reviewed in the HAZOP and Final Hazards Analysis as it is possible that further risk mitigation measures are justifiable. Specifically, these studies should address the hydrogen sulphide and sulphur dioxide isolation systems, emergency procedures and any additional release preventative measures. The effects at the nearest site boundary (ie particularly due to gas releases from the sulphuric acid plant) may be more realistically assessed and would be expected to be less than those predicted in this PHA.

7 REFERENCES

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ATTACHMENT 1

Materials Listing

Preliminary Hazard Assessment for the Syerston Nickel – Cobalt Project, Fifield, NSW

Attachment 1 – Materials Listing

Chemical Name Common Name Trade Name	Class	Storage Conditions Temp / Pressure °C, kPa	Inventory Average / Maximum	Storage Type
Sulphur Handling and Sulphuric Acid Plant				
Sulphur (site)	4.1	Atmospheric	Various / 10 000 te	Stockpile (prills / dust)
Sulphur (port)	4.1	Atmospheric	Various / 30 000 te	Stockpile (prills / dust)
Hydrated Lime	-	Atmospheric	Various / 25 te	Hydrated lime silo
Sulphuric Acid (>98 wt%)	8	25 / Atmospheric	Various / 10 000 te	One atmospheric tank
Sulphur Dioxide	2.3	80 – 800 / 24	-	In process piping and equipment
Sulphur Trioxide	8	80 - 500 / 24	-	In process piping and equipment
Sulphur Waste	-	Atmospheric	-	60 wt% sulphur, 40 wt% diatomaceous earth, ash and carbon
Natural Gas (for plant startup)	2.1	25 / 1000 - 3450	-	In process equipment and piping
Limestone Slurry Preparation				
Limestone	-	Atmospheric	Various / 25 000 te	Stockpile Limestone slurry pumped to neutralisation circuits
Hydrogen Sulphide Plant				
Hydrogen Sulphide (liquid)	2.3	60 / 1 200	Various / 72 te	In process piping and equipment
Sulphur (molten)	4.1	130 / Atmospheric	Various / 2 000 te	In process piping and equipment (tank)
Hydrogen	2.1	40 / 1 500	-	In process piping and equipment
Sulphur Dioxide	2.3	800 / Atmospheric	-	From flare stack

Chemical Name Common Name Trade Name	Class	Storage Conditions Temp / Pressure °C, kPa	Inventory Average / Maximum	Storage Type
Natural Gas (for flare)	2.1	25 / 1000 - 3450	-	In process equipment and piping
Hydrogen Plant				
Hydrogen	2.1	40 / 900	-	In process piping and equipment
Natural Gas (for reformer)	2.1	25 / 1000 - 3450	-	In process equipment and piping
Combustion Gases (eg carbon monoxide)	2.3	40 – 800 / 2000	-	In process equipment and piping
Oxygen and Nitrogen Production				
Oxygen (liquid)	2.2	-183 / 101	Various / 120 te	VIE Tanks (Vacuum Insulated Expander)
Nitrogen (liquid)	2.2	-196 / 101	Various / 15 te	VIE Tank (Vacuum Insulated Expander)
Reagent Storage Area				
Caustic Soda (50 wt% - for solvent extraction)	8	20 / Atmospheric	Various / 200 m^3	Atmospheric storage tank (fixed roof)
Magnesia (for neutralisation, ie in the solvent extraction and impurity removal areas)	-	Atmospheric	- / 500 te	Magnesia (MgO) bin
Flocculant (HP800 – used in thickeners)	-	Atmospheric	- / 10 te	Bulk bags
Flocculant (Magnafloc 155 – used in thickeners)	-	Atmospheric	- / 25 te	Bulk bags
Na_2SO_4 (sodium sulphate – Ni/Co electrowinning)	-	Atmospheric	- / 300 te	Bulk bags

Chemical Name **Common Name** **Trade Name**	**Class**	**Storage Conditions** **Temp / Pressure °C, kPa**	**Inventory Average / Maximum**	**Storage Type**
Power and Steam				
Steam (superheated)	-	450 / 6 000	-	In process piping and equipment
Steam (saturated)	-	276 / 6 000	-	In process piping and equipment
Steam (saturated)	-	165 / 600	-	In process piping and equipment
Condensate	-	90 / 300	-	In process piping and equipment
Natural Gas (for gas turbines, aux. steam boiler and HRSG firing)	2.1	25 / 1000 - 3450	-	In process equipment and piping
Oxides of Nitrogen	2.3	800 / Atmospheric	-	In process piping and equipment
Combustion Gases	-	800 / Atmospheric	-	In process piping and equipment
Natural Gas Distribution				
Natural Gas (high pressure)	2.1	25 / 3450	-	In process piping and equipment
Natural Gas (low pressure)	2.1	25 / 1000	-	In process piping and equipment
Water Supply				
Bore Water	-	25 / Atmospheric	2 000 m^3 30 000 m^3	Steel tank, fixed roof Dam, HDPE lined
Water Treatment				
Sulphuric Acid (5 wt%)	8	25 / Atmospheric	Various / < 1 te	Containers
Caustic Soda (5 wt%)	8	25 / Atmospheric	Various / < 1 te	Containers
Demineralised Water	-	25 / Atmospheric	-	In process piping and equipment
Potable Water	-	25 / Atmospheric	-	In process piping and equipment

Chemical Name Common Name Trade Name	**Class**	**Storage Conditions Temp / Pressure ^{o}C, kPa**	**Inventory Average / Maximum**	**Storage Type**
Chlorine	2.3	Atmospheric / saturated vapour pressure	- / 68 kg	Two G – size cylinders (at potable water tank)
Leach Water	-	25 / Atmospheric	Various / 700 m^3	Fixed roof tank
Fuel Storage				
Diesel (at the mine site process plant area)	-	25 / Atmospheric	Various / 50 m^3	Fixed roof tank (doubled walled for containment)
Diesel (mining contractor storage)	-	25 / Atmospheric	Various / 100 m^3	Two fixed roof tanks (same size, both bunded))
Diesel (storage at the limestone mine)	-	25 / Atmospheric	Various / 50 m^3	Fixed roof tank (bunded)
Diesel (storage at the rail siding)	-	25 / Atmospheric	Various / 50 m^3	Fixed roof tank (bunded)
Diluent (Shellsol 2046 – solvent extraction)	-	Atmospheric	- / 5 te	Storage tank
Compressed Air				
Plant Air	2.2	30 / 1 000	7.4 m^3	In the plant air receiver
Instrument Air	2.2	30 / 700 to 1 000	37.7 m^3	In 3 separate instrument air receivers
Cooling Water				
Cooling Water	-	27 / 350	NA	In a closed loop cooling water circuit
Tailings Dam				
Plant Tailings	-	Atmospheric	Various / 80 000 m^3 Area = 170 hectares	Tailings dam Evaporation pond
Limestone Slurry	-	Atmospheric	-	Pumped to tailings dam

Chemical Name Common Name Trade Name	**Class**	**Storage Conditions Temp / Pressure ^{o}C, kPa**	**Inventory Average / Maximum**	**Storage Type**
Carbon Dioxide	2.2	Atmospheric	-	Vent gas from neutralisation process
Ore Processing Plant				
Nickel Cobalt Ore	-	Atmospheric	Various / 100 000 te	Stockpile
Sulphuric Acid Solution (containing metals)	8	230 / 4100	-	In process piping and equipment
Carbon Dioxide (from neutralisation stage)	2.2	Atmospheric	-	Vent gas from neutralisation process
Vents streams and process piping containing: Hydrogen Sulphide Oxygen Oxides of Nitrogen Hydrogen	As above	As above	As above	As above
Export cobalt cathode	-	Atmospheric	400 te / -	250 kg drums back-loaded in sulphur containers
Export nickel cathode	-	Atmospheric	2 200 te / -	250 kg drums or 2 te pallets of full plate cathode back- loaded in sulphur containers
Export mixed nickel cobalt sulphide powder	-	Atmospheric	-	Bulk bags
Export cobalt hydroxide precipitate	-	Atmospheric	-	Bulk bags
Gypsum (calcium sulphate)	-	Atmospheric	-	In process equipment and piping (neutralisation stage)
Diluent (Shellsol 2046 – solvent extraction)	-	40 / 300	-	In process piping and equipment
Metal hydroxides (eg nickel, cobalt, lead)	-	Atmospheric	-	Filter cake

Chemical Name **Common Name** **Trade Name**	**Class**	**Storage Conditions** **Temp / Pressure** **°C, kPa**	**Inventory Average / Maximum**	**Storage Type**
Chemical Store				
Antiscalant (raw water treatment)	-	Atmospheric	- / 1 te	1 te Bulkibox
Barium Hydroxide (for lead removal)	6.1	Atmospheric	- / 30 te	1 te Bulk bags
Boric Acid (nickel electrowinning)		Atmospheric	- / 6 te	1 te Bulk bags
Bromine (cooling water biocide)	8	Atmospheric	- / 1 te	1 te Bulkibox or 205 L drums
Carbon (solvent extraction area)	4.2	Atmospheric	- / 1 te	Sealed 205 L drums
Catalyst (acid plant)	-	Atmospheric	- / 130 m^3	Bulk bags
Catalyst (desulphurising)	-	Atmospheric	- / 250 L	205 L drums
Catalyst (hydrotreating)	-	Atmospheric	- / 250 L	205 L drums
Catalyst (steam reformer)	-	Atmospheric	- / 1 800 L	205 L drums
Catalyst (shift conversion)	-	Atmospheric	- / 1 700 L	205 L drums
Coagulant (368 – used in the ore feed thickener)	-	Atmospheric	- / 20 te silo	Bulk bags
Corrosion inhibitor for boiler feed water	-	Atmospheric	- / 1 te	1 te Bulkibox
Corrosion inhibitor for cooling water	-	Atmospheric	- / 1 te	1 te Bulkibox
Cyanex 272 (extractant used in solvent extraction area)	-	Atmospheric	- / 2 te	1 te Bulkiboxes
Demin ion exchange resin	-	Atmospheric	- / 2 000 L	205 L drums

Chemical Name Common Name Trade Name	**Class**	**Storage Conditions** **Temp / Pressure ^{o}C, kPa**	**Inventory Average / Maximum**	**Storage Type**
Desiccant (instrument air)	-	Atmospheric	- / 400 L	205 L drums
Diatomaceous earth (for lead removal and sulphur filters)	-	Atmospheric	- / 100 te	Bulk bags
Dust suppressant for sulphur stockpile (diluted with water)	-	Atmospheric	- / 2 te	Bulkiboxes
Gelatine (covers cobalt EW plates)	-	Atmospheric	- / 1 te	Bulk bags
Glycol (for the seal water system)	-	Atmospheric	- / 1 te	Bulkiboxes
Grinding media – high density alumina 10 mm (ore preparation area)	-	Atmospheric	- / 25 te	205 L drums
Grinding media – steel 80 mm (ore preparation area)	-	Atmospheric	- / 200 te	205 L drums
Hydrochloric acid	8	Atmospheric	- / 200 L	205 L drum
Ionol – C272 (preservative used in solvent extraction area)	-	Atmospheric	- / 200 kg	Bulkiboxes
Nitric acid 60 wt% (Co EW cathode preparation area)	8	Atmospheric	- / 20 te	Bulkiboxes
Oxygen scavenger (boiler feed water)	-	Atmospheric	- / -1 te	Bulkibox
Scale inhibitor for boiler feed water	-	Atmospheric	- / 200 L	205 L drum
Scale inhibitor for cooling water	-	Atmospheric	- / 800 kg	205 L drums
Sodium Lauryl Sulphate (nickel electrowinning)	-	Atmospheric	- / 200 L	205 L drums

Chemical Name Common Name Trade Name	**Class**	**Storage Conditions Temp / Pressure ^{o}C, kPa**	**Inventory Average / Maximum**	**Storage Type**
TBP (tertiary butyl phosphate - phase modifier used in solvent extraction area)	-	Atmospheric	- / 1 te	Bulkibox

ATTACHMENT 2

Consequence Models Listing

Preliminary Hazard Assessment for the Syerston Nickel – Cobalt Project, Fifield, NSW

Attachment 2 – Consequence Models Listing

Consequence Calculations by Using Riskcurves (and Effects)

Riskcurves is a software package developed by TNO, the Netherlands Organisation for Applied Scientific Research, to perform quantitative risk calculations. The programme performs consequence calculations for user defined hazardous incident / release scenarios, estimates the effects on people and combines these results with incident frequency information, plant grid information and population data to determine risk. The risk results may be presented as individual risk contours, societal risk curves or risk transects.

Consequence and effects models in Riskcurves are fully described in the well known "Yellow Book" [1] and "Green Book" [2]. The consequence and effects modelling components of Riskcurves are also available as stand alone computer packages (Effects and Damage respectively). A brief listing and description of the relevant consequence models to this study used by Riskcurves is presented below.

1 Hazardous Incidents

1.1 Release Rates

Riskcurves can model release behaviour for compressed gas, liquid or 2-phase releases from vessels, pipelines or total vessel rupture. Data supplied by the analyst includes the type of release, the material, location of release with respect to vessel geometry, pipe lengths etc and initial conditions of the fluid (i.e. before release).

Gas Releases:

The equations for prediction of gas flowrates though orifices are well known and not reproduced here. Two cases are distinguished, sonic and subsonic flow. Sonic flow usually occurs when the ratio of the pressure of the gas to atmospheric pressure (assuming the release goes to atmosphere) is greater than 2.

For this study, gas release from either a vessel or pipe is modelled. The initial release rate depends on the leak size, the discharge coefficient and the initial pressure inside the vessel or pipe. For pipes, the friction resistances of the flow through the pipe also affects the release rates. For the larger hole sizes where the initial release rates are in excess of the gas production rates, the system pressure will drop and therefore the release rate decreases with time. The rate of decrease depends mainly on the system volume.

Included in the model output are:

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[1] "The Yellow Book", Methods for the Calculation of the Physical Effects of the Escape of Dangerous Material, CPR 14E, Parts 1& 2, Committee for the Prevention of Disasters, 3rd edition 1997

[2] “The Green Book”, *Methods for the Determination of Possible Damage, CPR 16E,* TNO Institute of Environmental Sciences, Energy Research and Process Innovation, 1st edition1992

- The mass flow rate and diameter of the expanded jet at time t
- The pressure and temperature at time t of the gas inside the system

2 Dispersion

2.1 Atmospheric Conditions

The gas dispersion process depends on meteorology, in particular on atmospheric turbulence. The meteorological conditions that are of prime importance are those in the lower part of the atmosphere where the releases take place. This region is known as the atmospheric boundary layer or mixed layer. The two main meteorological conditions that effect dispersion are the combination of wind direction and speed, and the atmospheric stability.

The wind flow in this layer is almost always turbulent. The turbulence is produced:

- Mechanically through the resistance of the earth's surface on the wind. This wind shear effect provides a downward turbulent momentum flux and depends mainly on the upper wind speed and the surface roughness.
- Thermally, through heating of the surface (primarily by the sun). This causes regions of hot air near the surface to rise, resulting in an upward turbulent heat flux.

Atmospheric stability determines the degree of mixing. When regions of air move upwards from the earth's surface, expansion due to the pressure decrease will result in a decrease in temperature. When the air has the same temperature as its surroundings during its travel upwards, no forces due to density differences are exerted on the air and the atmospheric stability is referred to as neutral. Stable conditions occur when the air is at a lower temperature than the surroundings and is thus forced downwards; unstable conditions pertain when its temperature is higher and is thus accelerated upwards. Dispersion is greatest in unstable conditions and least in stable conditions.

The stability of the mixed layer is determined by the ratio of turbulence generated by the temperature gradient and that generated mechanically by wind shear at the surface. Neutral or stable conditions tend to prevail at night and unstable conditions during the day, with a high degree of instability occurring on days of strong insolation and gentle winds.

Qualitative schemes are often used to characterise atmospheric stability, in dispersion modelling the most commonly used is the Pasquill scheme. This scheme ranks stability from class A (unstable) through D (neutral) to F (stable) and is based on observations of wind speed, cloud cover and time of day. Table A2.1, reproduced from Lees lists the stability classes relevant to various weather conditions.

Table A2.1 – Pasquill's Stability Categories

Surface wind	Insolation			Night	
Speed (m/s) at 10 m height	Strong	Moderate	Slight	Thinly overcast or ≥ 4/8 cloud	≤ 3/8 cloud
< 2	A	A-B	B	-	-
2 - 3	A-B	B	C	E	F
3 - 5	B	B-C	C	D	E
5 - 6	C	C-D	D	D	D
> 6	C	D	D	D	D

Meteorological data used by Riskcurves in the dispersion calculations is input by the user. The weather data is divided into 6 Pasquill stability classes and average windspeeds, with 12 directional probabilities for each windspeed / stability class combination.

2.2 Dispersion Models

The dispersion model used is selected by the analyst within Effects, depending on release conditions and behaviour, e.g. velocity, density of fluid.

Material that is released into the atmosphere will be dispersed by atmospheric turbulence. This process, known as dispersion, can be considered to start once the puff, jet or plume of material begins to interact with the ambient air. Instantaneous or short duration releases result in a puff of dispersing material; continuous releases result in jets or plumes, depending upon whether the released material possesses significant initial momentum. When the released material is hazardous, the effect on neighbouring populations must be assessed.

The lower part of the atmosphere where such releases take place, known as the mixed layer, is characterised by turbulent wind flows. This turbulence is produced mechanically, through wind shear caused by friction with the earth's surface, and thermally, through heating of the earth's surface by the sun. The first of these processes is produces a downward turbulent momentum flux, the second an upwards turbulent heat flux.

Turbulent eddies resulting from these fluxes act to transport and dilute (disperse) material released into the atmosphere. These eddies cover a range of sizes from several hundred metres down to millimetres. Eddies whose dimensions are significantly larger than those of the cloud will displace the dispersing release without altering its size or geometry. Eddies that are smaller will dilute the release and increase its size. Eddies of comparable size act to change the geometry of the cloud. Since the size of the cloud increases as it dilutes, the proportion of eddies contributing to displacement decreases while that contributing to dilution increases.

For continuous releases, large eddies act to displace the plume centre line. An appropriate averaging time must therefore be defined in order to determine concentration and plume width. The specification of the averaging time is relevant from a consequence point of view since consequences occur over a range of time scales, from almost instantaneously (e.g. combustion) to tens of minutes (e.g. toxicity effects).

2.2.1 Passive Dispersion

When the dispersion of a puff or plume of material is governed solely by atmospheric turbulence, the dispersion is said to be passive, i.e. the model should only be used for gases with a density approximately the same as air or if the gas concentration at the point of release is low.

Assuming that the turbulence and wind speed are the same at all locations in the surroundings, it can be derived that the concentration distribution of a cloud will be Gaussian in shape. In practise, Gaussian distributions are observed in many situations and therefore the passive dispersion model in Riskcurves is based on this type of distribution. Gaussian dispersion calculations are based on three parameters; σ_x , σ_y and σ_z, which are used to predict longitudinal, horizontal and vertical dispersion behaviour. Riskcurves uses the formulas by Van Ulden and Draxler to estimate these parameters. The variables used are surface roughness, averaging time and windspeed.

Simulations can be performed for continuous, instantaneous, semi-continuous or time dependent releases. The following types of calculations can be performed:

- Determination of gas concentration at a nominated position
- Determination of a selected gas concentration contour
- Determination of the amount of gas within the explosive range
- Determination of the toxic load ($C^n t$) at a nominated point

2.2.2 Jets

Gases or vapours which are released with high velocity will cause jets. As long as the velocity inside the jet is high compared to velocities in the ambient air, the extent of mixing in the jet will only be affected by the properties of the jet itself. The velocity difference between the jet and the surrounding air generates fine scale turbulence, which causes the jet to spread sideways. The velocity in the jet decreases with distance from the release source. At a certain distance the jet velocity will be reduced to such an extent that passive dispersion takes over.

Because the turbulent jet model is valid up to the distance where the gas velocity reaches the wind velocity, in most cases the model is not valid for low concentrations like toxic threshold. Therefore, only the flammable properties are calculated.

2.2.3 Plumes

Plume dispersion occurs when the material released into the atmosphere rises because it is either buoyant (less dense) than the ambient or because it possesses upward momentum. The released material will rise until it reaches a height where the momentum or buoyancy effects have been dissipated by dilution or where the material is in equilibrium with its surroundings. Once the material has reached this height, the dispersion may be assumed to be passive.

The Ooms plume path model is used to calculate the plume path, gas velocity, density and concentration due to gases emitted by a stack or similar situations. The pressure at the point of release is assumed to be essentially atmospheric. The Ooms model is extended with the dispersion perpendicular to the plume axis, which is assumed to be Gaussian and calculated with the neutral gas dispersion model.

3 Toxic Impact

The effect of exposure to toxic materials is predicted using probit equations. The calculated probit can be mathematically transformed (using the error function) allowing a probability of fatality to be predicted for a particular toxic load or dose. Riskcurves contains a set of default probits for common toxic materials, however a user defined probit may also be used. The equations are of the form:

Probit = $A + B \ln(C^n t)$

where C concentration (ppm)

t exposure time (min)

Probability of fatality = $\frac{1}{2}\left(1 + \mathrm{erf}\left(\frac{\mathrm{Pr} - 5}{2^{0.5}}\right)\right)$

The dispersion results are presented in terms of toxic load (dose) rather than concentration. Dose is calculated within Riskcurves by integrating the concentration at a particular location over the exposure duration. The concentration may vary over time. The duration is the lesser of the time taken for the cloud to pass or the maximum exposure duration (a parameter set by the analyst). For this study a maximum exposure duration of 1 hour has been set.

4 Fires and Heat Radiation

Heat radiation effects from various fires are calculated based on flame surface emissive power (SEP) which is dependent on the quantity of material, its heat of combustion, flame dimensions and the fraction of heat radiated. The heat flux at a particular distance from a fire is calculated using a view factor method. The view factor takes into account the distance from the flame to the target, the flame dimensions and the orientation angle between the flame and the target. It is defined as the fraction of the field of view at the receiving surface which is filled by the flame.

Note that the calculations of view factor and SEP are different for different types of fires but the general formula used to estimate the radiation intensity at a distance from the flame (i.e. at a receptor) is:

$I = SEP \times F \times \tau$

where I = heat radiation intensity at point of interest (kW/m^2)

SEP = surface emissive power (kW/m^2)

F = view factor

τ = atmospheric transmissivity (calculated from carbon dioxide and water content in air)

For flames / materials where an estimation / empirical measurement of SEP is not available, the SEP is calculated based on the fraction of combustion energy that is emitted from the flame as thermal radiation. These fractions or correlations for estimating them are available in the literature for various materials and types of flame.

4.1 Jet Fires

Jet fires are modelled using the Chamberlain model. The model is based on simulating the flame shape as a frustrum of a cone. The flame stability, shape, orientation and total radiative flux are described by a set of semi-empirical correlations which have been developed from and validated against a wide range of laboratory wind tunnel tests and large scale field trials (both on-shore and off-shore).

The flame is defined as a solid body which emits radiation with uniform surface emissive power. The model is developed for flaring hydrocarbon gas under a variety of process conditions. Experimental tests have shown that the fraction of heat radiated from a flame decreases with increasing gas exit velocity. This is because with a higher gas velocity a larger fraction of heat is lost by convection to the entrained air. This correlation is incorporated into the model.

Included in the model output are:

- The heat radiation flux at a distance (x) away from the flame
- The surface emissive power (see above)
- The flare (jet) dimensions, including flame tilt and lift-off

4.2 Pool Fires

The pool fire model uses an average radiation intensity which depends on the liquid combustion rate. The combustion rate of the liquid can be manually set or calculated using the available combustion model.

In the pool fire heat radiation model account is taken of the diameter-to-height ratio of the fire, which also depends on the burning liquid and pool size. It is assumed that the fraction of heat radiated from a pool fire is 0.35 (although this can be modified if necessary). Also taken account in the model is the tilt of the pool fire flames. This tilt depends on the wind velocity and the vapour density difference between air and the burning liquid.

Included in the model output are:

- The heat radiation flux, view factor and atmospheric transmissivity at a distance (x) away from the flame
- The surface emissive power (see above)
- The angle of the pool fire flames (relative to the vertical centreline)

4.3 Heat radiation effects on people

The effect of heat radiation on a person is calculated from a probit equation and the probability of fatality predicted by transforming the probit to a probability of fatality. The probit used is a version of the Eisenberg equation corrected for infrared radiation as experienced from fires (rather than UV from nuclear blasts that some earlier equations were based on).

Probit = $-36.38 + 2.56 \ln(tQ^{4/3})$

Where		
	t	exposure time (sec)
	Q	heat flux (W/m^2)

Probability of fatality = $\frac{1}{2}\left(1 + \mathrm{erf}\left(\frac{\mathrm{Pr}-5}{2^{0.5}}\right)\right)$

Note that this heat radiation probit is only valid for very short exposure durations (less than 1 minute). For the purposes of this risk assessment it is assumed a person has 20 seconds to escape from heat radiation (i.e. an exposure duration of 20 seconds).

ATTACHMENT 3

Meteorological Data

Preliminary Hazard Assessment for the Syerston

Nickel – Cobalt Project, Fifield, NSW

Attachment 3 – Meteorological Data

Six typical weather / wind combinations (Pasquill stability category / wind speed) have been used as the basis for all dispersion calculations. The probability of each combination of weather / wind category and wind direction (any of 16 directions) is used in the calculation of toxic impact. The weather / wind data (Table A3.1 below) is a consolidated (reduced) version of detailed weather / wind conditions for the period May 1999 to April 2000, from the nearby Peak Hill station.

Table A3.1 – Percentages of Occurrence of Weather / Wind Combinations with Wind Direction

Wind Direction	**Stability Class / Windspeed (m/s)**					
	B3.4	**C5.4**	**D2**	**D5.4**	**E2**	**F2**
N	1.43	1.25	1.33	1.79	0.62	0.97
NNE	1.08	1.03	1.73	1.64	0.75	0.86
NE	1.42	1.36	1.83	2.09	1.49	0.99
ENE	1.22	1.13	2.17	2.39	1.32	0.92
E	0.78	1.08	1.91	1.28	1.09	1.53
ESE	0.71	0.47	2.12	0.64	1.00	2.16
SE	0.67	0.29	1.33	0.28	1.67	2.60
SSE	0.67	0.50	1.43	0.33	1.75	1.83
S	1.01	0.82	2.02	0.78	1.56	1.32
SSW	0.78	0.80	1.88	1.23	0.89	0.93
SW	0.93	0.97	1.31	1.26	0.61	1.02
WSW	1.05	0.72	1.22	0.79	0.58	0.85
W	0.90	0.43	0.82	0.35	0.18	0.65
WNW	0.69	0.48	0.54	0.14	0.21	0.57
NW	1.00	0.49	0.78	0.41	0.25	0.56
NNW	1.29	0.69	0.91	0.58	0.32	0.50
Proportion (sum = 100%)	15.63	12.52	23.33	15.98	14.27	18.26

ATTACHMENT 4

Toxicity Data

Preliminary Hazard Assessment for the Syerston Nickel – Cobalt Project, Fifield, NSW

Attachment 4 – Toxicity Data

Properties of Hazardous Materials

4.1 Toxicology

Toxicology is a very complex subject, and toxicity of materials is difficult to quantify. Some indication of the toxic hazard potential is given by exposure limits and IDLH concentrations. This data is summarised in Table A4.1 below.

Exposure limits relate primarily to occupational exposure. The limits are generally time-weighted average (TWA) concentrations for up to a 10-hour workday during a 40-hour working week. A short-term exposure limit (STEL) is a 15 minute TWA exposure that should not be exceeded at any time during a workday. A ceiling value should not be exceeded at any time.

Immediately Dangerous to Life and Health concentrations (IDLH's) represent the maximum concentration from which one could escape within 30 minutes without experiencing any escape-impairing (e.g. severe eye irritation) or irreversible health effects.

Odour threshold values are also shown. This is essentially the level at which a substance can be detected, although not necessarily identified by all people, and acts as a warning of the presence of a material. Note that an odour threshold for a particular material has no relationship to the dangerous concentration of that material, i.e. the odour threshold may be higher or lower than a harmful level.

Table A4.1 - Toxicological Data

(Ref A4.1, A4.2, A4.3)

Material	Odour Threshold (ppm)	Exposure Limit (ppm)		IDLH (ppm)	Comments
		TWA	STEL/CEILING		
Hydrogen Sulphide	0.13	10	15 (STEL)	100	Poisonous, Irritant
Sulphur Dioxide	1	2	5 (STEL)	100	Irritant

4.2 Fatality Prediction

In order to quantify the risk from toxic releases probit equations are used to estimate the probability of fatality based on concentration and duration of exposure. The relationship between probit and probability of fatality is then determined from the standard probit curve or table (Ref A4.4).

For this analysis, the probit equations used to predict fatality risk from hydrogen sulphide and sulphur dioxide are:

Hydrogen sulphide: $Pr = -40.35 + 2.90 \ln (C^{2}T)$

Sulphur dioxide: $Pr = -23.7 + 1.14 \ln (C^{3.7}T)$

where:

Pr = the probit value

C = concentration (in ppm)

T = duration of exposure (in minutes).

Both probits are taken from the SHE Pacific HAZAN course notes and are regarded as being conservative, i.e. it is expected that the probability of fatality will be overestimated for a given dose.

A check against the calculated results from the probits used in Riskcurves (Quantitative risk assessment software, TNO, Ref A4.5) for both chemicals was performed. Table A4.2 shows the difference in predicted probits for selected toxic loads. It can be seen, that of the two probits reviewed, the equation from the SHE Pacific HAZAN course notes generally predicts the most severe effects for a given dose (i.e. is the most conservative).

All results in the table are for an exposure time of 10 minutes. For both equations, the units are time in minutes and concentration in ppm.

Table A4.2 - Comparison of Fatality Probits

Probit Description	**Probability of fatality for 10 minute exposure for stated concentration**		
Hydrogen sulphide concentration:	500 ppm	1000 ppm	2000 ppm
SHE Pacific HAZAN course notes:	0	92	100
TNO: $Pr = -10.83 + \ln (C^{1.9}T)$	4	34	82
Sulphur dioxide concentration:	300 ppm	500 ppm	700 ppm
SHE Pacific HAZAN course notes:	2	55	94
TNO: $Pr = -16.84 + \ln (C^{2.4}T)$	0	0	0

4.3 Injury Prediction

4.3.1 Injury Risk Criteria:

Injury due to toxic exposure depends on the nature of the material, the concentration, the duration and mode of exposure and also on the sensitivity of the person exposed. It therefore follows that toxic criteria applicable to one chemical will not necessarily be appropriate for another chemical. The approach required by DUAP is to assess each case on its merits based on known dose-effect relationships for a particular chemical, (viz, Ref A4.6 pg 5 *"Toxic criteria applicable to one chemical may not necessarily be appropriate to others. The department's experience conclusively shows that the formulation of a uniform criteria to cover all toxic effects is not appropriate or valid. Instead, each case should be justified on its merits....").*

Unlike fire and explosion risk where exposure effects (caused by thermal radiation intensity or overpressure respectively) corresponding to the injury criteria are clearly documented by DUAP, toxic risk criteria for injury are not specified but are left to the assessor to determine. To determine what "dose" should be used to assess injury risk the following exposure effects guidelines are suggested by DUAP (Ref A4.6):

Injury:

"Toxic concentrations in residential areas should not exceed a level which would be seriously injurious to sensitive members of the community following a relatively short period of exposure at a maximum frequency of 10 in a million per year."

Irritation:

"Toxic concentrations in residential areas should not cause irritation to eyes or throat, coughing or other acute physiological response in sensitive members of the community over a maximum frequency of 50 in a million per year."

Establishing the appropriate criteria for a particular chemical necessitates determination of the terms "seriously injurious", "sensitive", "relatively short" and "irritation". The American Industrial Hygiene Association's Emergency Response Planning Guidelines (Ref A4.7) provide data on "injury" toxic exposure levels for a few industrial chemicals for exposure periods of one hour. Three sub-fatal toxic exposure levels are defined by the American Industrial Hygiene Association (AIHA). The definitions are as follows:

ERPG:

Emergency Response Planning Guidelines are values intended to provide estimates of concentration ranges above which one could reasonably anticipate observing adverse health effects; see ERPG-1; ERPG-2; ERPG-3. The term also refers to the documentation that summarises the basis for those values. The documentation is contained in a series of guides produced by the Emergency Response Planning Committee of the American Industrial Hygiene Association (Ref A4.7).

ERPG-1: The maximum airborne concentration below which nearly all individuals could be exposed for up to 1 hour without experiencing more than mild, transient adverse health effects or without perceiving a clearly defined objectionable odour.

ERPG-2: The maximum airborne concentration below which nearly all individuals could be exposed for up to 1 hour without experiencing or developing irreversible or other serious health effects or symptoms that could impair an individual's ability to take protective action.

ERPG-3: The maximum airborne concentration below which nearly all individuals could be exposed for up to 1 hour without experiencing or developing life-threatening health effects.

In terms of effects, the ERPG-2 and ERPG-3 definitions seem to approach most closely the "Irritation" and "Injury" guidelines suggested by DUAP, however with a 1 hour rather than “relatively short exposure period”. Table A4.3 summarises the injury and irritation effects and corresponding probability criteria.

Table A4.3 - Injury and Irritation Criteria

Consequence	Toxic Determination Method	Probability Criteria (set by DUAP)
Fatality	Via probit equation	1 x 10^{-6}/yr
Injury	ERPG-3 **Corresponding to**: No life threatening effects after 1 hr exposure	10 x 10^{-6} /yr
Irritation	ERPG-2 **Corresponding to**: No irreversible or serious health effects or symptoms which could impair an individuals ability to escape after 1 hr exposure	50 x 10^{-6} /yr

4.3.2 Determination of Appropriate Exposure Levels:

The Emergency Response Planning Guidelines provide a basis on which "injury" toxic exposure levels can be developed. These guidelines specify three toxic exposure levels for exposures of one hour's duration, ERPG-1, ERPG-2 and ERPG-3. For both hydrogen sulphide and sulphur dioxide, given that a relationship between toxic effect and concentration/exposure time (i.e. dose) exists, it can be inferred that for shorter exposure durations higher concentrations would apply to obtain an equivalent effect.

For sulphur dioxide, the ERPG 2 and 3 levels are 3 and 15 ppm, respectively. Given that the ERPG values are for an exposure duration of 1 hour, calculations were performed to determine irritation and injury concentrations for a 20 minute exposure (ie toxic load, C^nT, was assumed to be constant). Note that 20 minutes is the calculated maximum off-site exposure duration for any release of sulphur dioxide. The values of sulphur dioxide concentration selected for irritation and injury risk levels are therefore taken as 4 ppm and 20 ppm.

A conservative approach is adopted for the selection of irritation and injury hydrogen sulphide concentration levels has been taken (given a spread in reported hydrogen sulphide effect data). Reported data in Ref A4.3 for hydrogen sulphide has the following concentration / exposure time / effect relation ship:

70 – 150 ppm over 3 – 4 hours causing irritation effects

70 – 300 ppm over 1 hour is the maximum inhalable without serious effect

The data is taken as a guide to irritation and injury levels, respectively. As the exposure durations are large compared to the estimated times of exposure of people off-site to a potential cloud of hydrogen sulphide (approximately 7 minutes), the maximum values of each range are taken as the values for which irritation and injury occur in this study (ie no allowance is made for the reduced exposure time). Hence, for hydrogen sulphide, irritation and injury concentrations levels are taken as 150 and 300 ppm, respectively. These values are similar to the reported ERPG 2 and 3 values of 30 and 100 ppm, respectively, when corrected for the different exposure time for a given toxic effect (ie C^nT is constant).

References

A4.1 *Material Safety Data Sheets* (General information).

A4.2 *NIOSH Pocket Guide to Chemical Hazards,* US Department of Health and Human Services, June 1990 (Exposure limits and IDLH's)

A4.3 *Loss Prevention in the Process Injuries*, 2nd Edition, Frank P Lees, 1996

A4.4 *Guidelines for Chemical Process Preliminary Hazard Analysis,* American Institute of Chemical Engineers, 1989 (Probits)

A4.5 *Methods for the Determination of Possible Damage*, TNO, 1992

A4.6 *Hazardous Industry Planning Advisory Paper No 4 (HIPAP4),* Department of Urban Affairs and Planning, 1992

A4.7 *Emergency Response Planning Guidelines*, American Industrial Hygiene Association, 1988

Prepared for
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Transport Assessment for the Proposed Syerston Nickel-Cobalt Project

August 2000

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1. Introduction

This report relates to transport implications of a proposal to develop the Syerston nickel-cobalt project at Fifield. The project and its ancillary infrastructure spans the Lachlan, Parkes and Forbes Shire Council areas.

The report provides a specialist analysis of transport aspects for inclusion in an Environmental Impact Statement. The Director of the Department of Urban Affairs and Planning's requirements relating to transport aspects of the EIS are provided in Attachment A.

The report has been written and finalised in consultation with the Transport Sub-Committee which has met several times to discuss transport issues relevant to the Syerston project. The Transport Sub-Committee evolved from the Steering Committee for the Syerston Project and includes representatives of Lachlan Shire Council, Parkes Shire Council, Forbes Shire Council, Roads and Traffic Authority, Black Range Minerals, Resource Strategies and Masson Wilson Twiney.

The location of the mine in relation to Fifield is shown in Figure 1 of this report. The location of the mine and the transport system serving it are indicated on Figures 2 and 3.

A description of the project is provided in Chapter 3 of this report. In brief it is proposed that the mine employ 371 persons and produces about 2 million tonnes per annum (tpa) of ore for initial processing on site. Either 20,000 tpa of nickel and 5,000 tpa of cobalt or about 42,000 tpa of nickel cobalt sulphide precipitate will be transported from the site.

Processing will require water and gas, which will be transported to the site by pipeline. It will also require about 560,000 tonnes per annum of limestone and 210,000 tpa of sulphur. Limestone will be transported by road from a nearby quarry. Sulphur will be transported by rail to a siding north of Trundle and transported by road from there.

Construction is expected to take about 24 months and at its peak nearly 1000 persons will be employed on the site during this time. A construction camp will be provided to accommodate these from month 7 of the construction period.

Chapter 2 of this report describes the existing transport system while Chapter 3 describes the proposal more fully. Chapter 4 examines transport implications of the proposal when operational. Chapter 5 considers transport implications during construction. Chapter 6 provides a summary and conclusions.

In conducting this investigation information and assistance has been provided by representatives of Lachlan and Parkes Shire Councils as well as Freight Rail, Brambles Limited and the Roads and Traffic Authority. Their assistance is gratefully acknowledged.

2. Existing Transport System

2.1 Road System

2.1.1 Road Network

The road system in the vicinity of the site is shown in Figure 2. Roads that would be used by traffic generated by the project are described below. The descriptions are indicative of the average conditions that a driver would experience along the route. Some sections of some routes have conditions that are better or worse than the average described.

State Route 90 connects Parkes and Condobolin through Bogan Gate and Ootha. The road has one lane in each direction and travels through flat terrain with overtaking generally allowed. The speed limit is 100 km/h. There are centre and edge line marking and guidance posts. The road generally has around 1 metre gravel (or grassed) shoulders. The road surface is in good condition. The road is subject to flooding with signage and depth markers at a number of dips and causeways along the route. Some 5 kilometres west of Parkes, there is a railway level crossing controlled by signals.

Main Road 350 (Tullamore – Bogan Gate Road) from Bogan Gate to Tullamore intersects with State Route 90 at a cross intersection in Bogan Gate with priority to traffic on State Route 90. The southern approach is an unpaved, minor road. There is an unpaved shoulder on the southern side of State Route 90 so that westbound vehicles can pass vehicles waiting to turn right towards Tullamore at the intersection. The pavement on the road to Tullamore is in generally good condition. It has a two lane sealed carriageway, centre line marking and guidance posts. The road shoulder is unpaved and varies in width from 0-2 metres. There are no painted edge lines to define the carriageway. There are a number of floodways and railway level crossings which are controlled by signs only. The speed limit is 100 km/h generally but 50 km/h through Trundle. There is a 40 km/h school zone for the school located on the southern side of Trundle. Residences in Trundle are set back 30-40 metres on either side of the road.

Shire Road 83 (Middle Trundle Road) runs north west from State Route 90 to intersect with MR350 just south of Trundle. This road provides a route which is just under 10 kilometres shorter between Parkes and Trundle than the route which travels through Bogan Gate. Intersections at both ends of the road are Type A intersections (refer to Attachment B for description of standard intersection types). The first half of the road immediately north west of State Route 90 is sealed and in good condition with centre line marking although most of its length does not have a shoulder. The second half of the road is unsealed to MR350. In this section there are a number of causeways where water crosses the road. The speed limit is 100 km/hr.

Shire Road 64 (Fifield –Trundle Road) intersects with the Road from Bogan Gate to Tullamore at a Type A T-intersection some 6 kilometres north of Trundle. Shire Road 64 is generally around 4 metres wide with about 1 metre wide gravel shoulders. The paved roadway widens on crests and at curves. There is limited linemarking. The road has some potholes but is generally in fair condition. There are some causeways on the road. At the western end of the road, it intersects with Main Road 57 North at a Type A T-intersection.

Main Road 57 North runs north from State Route 90, east of Condobolin, though Fifield and Tullamore. The intersection with State Route 90 has a Type A configuration. There is a railway level crossing to the north of the intersection which is controlled by signals. The road surface is in good condition with a two lane seal. The speed limit is generally 100 km/h. There is no linemarking but guidance posts are provided. Shire Road 60 intersects with Main Road 57 North at a Type A intersection. Priority is to traffic on Main Road 57 North. The road pavement ends to the north-east of this intersection and the road becomes a gravel road with an 8-12 metre wide formation. There are a number of tight curves (some 90°) which require vehicles to reduce speed. North of its intersection with Shire Road 64, Main Road 57 (North) is paved with a two lane seal. There is limited linemarking and there are guidance posts and the road surface is in good condition. Approaching Fifield, the speed limit reduces to 50 km/h. The road doglegs through Fifield which has residences on either side of the road. About 1 kilometre north of Fifield, the road again becomes unpaved, with a formation width of about 12 metres. There is good sight distance at the existing site entry. There is a property entry opposite the existing entry to the proposed mine site. South of Tullamore, the road is again paved, with a marked centreline. There is a railway level crossing which is controlled by signs just south of Tullamore.

Shire Road 44 (Melrose to Gillenbine Road) runs east-west along the northern boundary of the site. It intersects with Main Road 57 north at a cross intersection. It is an 8-12 metre wide unpaved road which is generally straight and through flat terrain. It continues west from the site and intersects with Shire Road 60 at an offset cross intersection with priority to Shire Road 44. The speed limit is 100 km/h.

Shire Road 34 (Fifield to Wilmatha Road) runs north from Fifield, through the subject site and intersects with Shire Road 44 at a cross intersection. Shire Road 44 has priority at this intersection. It is an 8-12 metre wide unpaved road which is generally straight and through flat terrain. The speed limit is 100 km/h.

Shire Road 60 (Springvale Road) is a sealed road approximately 6 metres wide with the pavement in good condition. It has a 100 km/h speed limit and is generally straight and runs through flat terrain. It has good sight distance for the majority of its length. There is limited linemarking.

2.1.2 Existing Traffic Flows

Figure 2 indicates daily traffic volumes on roads most likely to be affected by the proposed mine. These counts have been conducted at various times during which there has been some variations in activity in the area. Nevertheless the counts are still indicative of general levels of traffic and for the most part indicate that they are very low, as would be expected on essentially local rural access roads.

Table 2.1 below summarises daily traffic volumes on roads leading to and from the mine site. Proportions of heavy (large rigid vehicles and articulated) vehicles are also indicated at sites where this information is available. The location and date of the counts are shown on Figure 2.

To put existing traffic flows in context a "Quality of Service" assessment is also provided on Table 2.1. Quality of Service relates daily traffic volumes to the standard of the road in order to give an indication of the driver's experience. The Quality of Service is not only dependent on capacity but includes such factors as road surface, road width, riding quality and ability of vehicles to travel at their desired speed Quality of Service criteria are provided on Table 2.2.

Table 2.1 – Existing Daily Traffic Volumes and Quality of Traffic Service Assessment

Road	Location (Year of Count)	Daily Traffic Flow	Percent Heavy Vehicles	Carriageway Description	Quality of Service
State Route 90	E of Bogan Gate (96)	792		2 lane seal	Good
MR350	Bogan Gate to Trundle (96)	388		2 lane seal	Good
MR350	N of Trundle (92)	339		2 lane seal	Good
SR83	E of MR350 (96)	99		Gravel(1) 2 lane seal	Fair/good
SR64	E of MR57 North (99)	52	17.1%	1 lane seal	Good
MR57 North	N of State Route 90 (96)	216		2 lane seal	Good
MR57 North	NE of SR60 (95)	87	10.6%	Gravel	Fair
MR57 North	S of Fifield (92)	63		2 lane seal	Good
SR44	E of SR60(2)	90		Gravel	Fair(2)
SR34	S of SR44(2)	90		Gravel	Fair(2)
SR60	N of MR57 Nth (99)	90	12.6%	2 lane seal	Good
MR57 North	S of Tullamore (96)	164		Gravel(3) 2 lane seal	Poor/good
MR57 North	N of Tullamore (96)	98	17.4%	Gravel	Fair
MR354	NW of Tullamore (99)	69		Gravel	Fair
MR354	20km NW of Tullamore (96)	373		Gravel	Poor

Source: Traffic Counts by Lachlan and Parkes Shire Councils and RTA
(1) Fair on gravel sections, good on sealed section
(2) No traffic data available, assume similar volumes to SR60 for worst case
(3) Poor on gravel sections, good on sealed section

Table 2.2 – Rural Arterial Road Service Assessment Criteria (vehicles/day)

Road Stereotype	Quality of Traffic Service		
	Poor	Fair	Good
UNSEALED			
Natural surface	Over 100	61 to 100	Up to 60
Formed	Over 100	61 to 100	Up to 60
Gravel one lane (up to 4.5m)	Over 100	61 to 100	Up to 60
Gravel two lane (over 4.5m)	Over 150	61 to 150	Up to 60
SEALED UNDIVIDED			
One lane (up to 4.5m)	Over 300	151 to 300	Up to 150
Narrow two lane (4.6 to 6.4m)	Over 4000	1001 to 4000	Up to 1000
Wide two lane (6.5 to 9.1m)	Over 6000	4001 to 6000	Up to 4000
Three lane (9.2 to 11.6m)	Over 10000	6001 to 10000	Up to 6000
Four lane (over 11.6m)	Over 15000	10001 to 15000	Up to 10000
DIVIDED			
Four lane (up to 9.1m x 2)	Over 30000	15001 to 30000	Up to 15000

Source: NAASRA Roads Study (1984)

Table 2.1 indicates that the roads which are sealed in the vicinity of the mine site and the principal ones leading to and from it presently exhibit 'Good' operating conditions. Those roads which are unsealed presently exhibit 'Fair' or 'Poor' operating conditions.

Quality of Service provides an overall indication of a driver's experience on a road based on average daily traffic volumes. However, traffic volumes tend to vary throughout the day resulting in varying traffic conditions. It is therefore appropriate to also examine the operation of roads during peak traffic flows in terms of capacity.

Table 2.3 below presents typical hour by hour proportions for roads in the area. The table was produced from several counts conducted by Parkes and Lachlan Shire Councils in 1999.

Table 2.3 – Typical Hourly Traffic Proportions Throughout the Day

Hour Period	Percent of Daily Flow
0000-0100	0.70
0100-0200	0.35
0200-0300	0.25
0300-0400	0.25
0400-0500	0.10
0500-0600	1.10
0600-0700	6.00
0700-0800	7.20
0800-0900	6.95
0900-1000	6.70
1000-1100	7.15
1100-1200	6.75
1200-1300	6.40
1300-1400	6.25
1400-1500	5.70
1500-1600	5.05
1600-1700	9.05
1700-1800	10.90
1800-1900	5.95
1900-2000	3.20
2000-2100	1.40
2100-2200	0.90
2200-2300	0.85
2300-2400	0.80

Source: 1999 Traffic Counts by Parkes and Lachlan Shire Councils

Table 2.4 presents indicative peak hour traffic flows for the mine's principal access routes derived using proportions indicated on Table 2.3.

Table 2.4 – Existing Peak Hour Flows (vehicles/hour)

Road	Location	AM Peak	PM Peak
State Route 90	E of Bogan Gate	57	86
MR350	Bogan Gate to Trundle	28	42
MR350	N of Trundle	24	37
SR83	E of MR350	7	11
SR64	E of MR57 North	4	6
MR57 North	N of State Route 90	16	24
MR57 North	NE of SR60	6	10
MR57 North	S of Fifield	5	7
MR57 North	S of Tullamore	12	18
SR44	E of SR60(1)	6	10
SR60	N of MR57 North	6	10

(1) No traffic data available, assume similar volumes to SR60 for worst case

The AUSTROADS guide[1] defines the theoretical capacity of a two lane two way road under ideal conditions as 2,800 vehicles per hour. A two lane two way road is the most basic road with a single stream of traffic travelling in each direction and vehicles required

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[1] AUSTROADS (1998), *Guide to Traffic Engineering Practice, Part 2 – Roadway Capacity*, Sydney.

to cross into the opposite carriageway to overtake. While the capacities of these routes would be somewhat less than this theoretical capacity, Table 2.4 indicates that peak hourly traffic flows are very low in comparison. Thus there are no road capacity issues relating to the existing road system and traffic volumes. The quality of service on the roads is therefore the governing factor in assessing the operation of the existing road system.

2.1.3 Intersection Operation

Intersections are generally the critical location in terms of traffic conflicts and capacity constraints within a road system. Experience has found that intersections carrying low traffic volumes operate satisfactorily under priority traffic controls. However above threshold levels other controls such as traffic lights or roundabouts may be needed. This is usually determined through detailed analysis.

Table 2.5 below sets out threshold limits for conflicting traffic volumes at intersections below which priority controls are all that are needed. For example, a two lane roadway carrying 400 vehicles per hour can have up to 250 vehicles per hour on the cross road before other intersection controls are needed. If the two lane roadway was carrying 650 vehicles per hour, the cross road could carry up to 100 vehicle per hour before other intersection controls were needed.

Table 2.5 – Intersection Traffic Flow Combinations Below which Priority Controls will Provide Good Operating Conditions (vehicles/hour)

Road Type	Maximum Design Hour Volume Combinations		
Two-lane through roadway	400	500	650
Cross Road	250	200	100
Four-lane through roadway	1000	1500	2000
Cross Road	100	50	25

Source: AUSTROADS Guide to Traffic Engineering Practice Part 5 Intersections at Grade 1988

Comparison of Table 2.5 with Table 2.4 indicates that peak hourly traffic flows on all intersecting roads are such that priority controls are all that are needed at intersections in the area.

2.1.4 Crash History

Crash data for local roads in the vicinity of the mine has been supplied by the RTA for the five year period 1/1/94 – 31/12/98 (the latest available). The data shows

- SR60 (MR57 North – SR44): 0 reported crashes
- SR44 (SR60 – MR57 North): 0 reported crashes
- MR57 North (State Route 90 – SR44): 2 admitted injury, 2 towaway crashes
- MR57 North (SR44 – Tullamore): 0 reported crashes
- MR350 (Bogan Gate – SR64): 1 admitted injury, 2 treated injury, 3 towaway crashes
- SR64 (MR350 – MR57 North): 1 towaway crash
- SR83 (State Route 90 – MR350): 1 treated injury crash.

An admitted injury crash is where one or more persons were admitted to hospital as a result of injuries sustained in the crash. A treated injury crash is where one or more persons are treated on the scene for injuries as a result of the crash. A towaway crash is one where nobody sustained treatable injuries but where one or more vehicles had to be towed from the scene.

The crash analysis shows that there are no ‘blackspot’ sites requiring immediate treatment. A ‘blackspot’ site is a location which has an abnormally high number of crashes.

2.1.5 Road/Rail Intersections

The principal routes serving the mine site cross railway lines at six locations as follows:

- State Route 90, Bogan Gate, west of MR350 – once
- MR350 Bogan Gate to SR64 – 3 times
- MR57 North, north of State Route 90 – once
- Rail siding access road – once

The MR57 North crossing is fitted with bells and flashing lights. The crossing on State Route 90 and the three crossings on MR350 have only warning signs at the level crossings. The existing railway level crossing at the access road to the proposed rail siding also has only warning signs.

2.2 Rail System

It is proposed to transport sulphur and other bulk materials to the site from Newcastle by rail and to back load products from the mine by rail. A new siding is proposed to be constructed north of Trundle on the existing Tottenham Bogan Gate railway near the intersection of MR350 and SR64. Rail transport from Sydney is also envisaged. These aspects are described in Chapter 3 of this report.

A logistics study has been prepared by Brambles Mining and Industrial Services for the Syerston Project. In summary, it states:

- The rail transport cycle between Newcastle and the proposed mine siding is 1,390 kilometres with an elapsed time of approximately 70 hours.
- There are two direct paths for transport from Newcastle to the site:
    1. The Newcastle – Hunter Valley – Ulan – Dubbo – Narromine – Parkes – The Troffs path is used for grain and coal transport through to the Port of Newcastle.
    2. The Newcastle – Central Coast – Sydney – Blue Mountains – Bathurst – Blayney – Orange – Parkes – The Troffs path. The railway over the Blue Mountains is shared with major passenger train and coal train movements. Priority is given to passenger trains and bulk goods trains are limited to periods outside of commuter peaks. There is accordingly limited spare capacity on this route.
- It is proposed to use the Newcastle-Dubbo path as this is the best route and has the capacity required for the transport of bulk materials to the site.
- It will however be necessary to use the Sydney – Blue Mountains path for rail transport of caustic soda sourced in Sydney.

3. Description of the Proposal

The proposal involves mining and processing on site of about two million tonnes of ore per annum. Processing involves treatment of the ore with sulphuric acid and other re-agents to produce either 20,000 tpa of nickel metal and 5,000 tpa of cobalt metal or 42,000 tpa of nickel cobalt sulphide precipitate.

The main bulk inputs to the process will be:

- sulphur – to be imported from overseas via Newcastle
- limestone – to be quarried locally
- caustic soda – to be transported from Sydney
- magnesia – to be transported from Young
- natural gas – to be piped in
- water – to be piped in

It is proposed that operations take place 24 hours a day. The life of the mine is expected to be in excess of 30 years with a build up to full production about two years after construction is complete.

Construction is expected to take about 24 months with minimal on site presence during the first 7 months. During the busiest month nearly 1000 persons are expected to work on site. A self contained construction camp is proposed to be provided for the workforce from month 7 of the construction period.

Once fully operational about 371 persons are expected to work on the site. About 100 of these are expected to be drawn from the local workforce and the balance with their families are expected to be new to the area.

Besides works on the mine itself, the proposal involves the following aspects:

- construction of a new rail siding on the Bogan Gate-Tottenham railway line near the intersection of SR64 with MR350
- construction of a limestone quarry adjacent to SR64
- upgrading of the route between the rail siding and the mine to a standard suitable for heavy truck haulage (includes part of MR350, SR64, part of SR34)
- construction of a bypass of Fifield around the south-western side of the village linking SR64 to SR34
- construction of water and gas pipelines to the site
- establishing eastern and western borefields to provide the projects water requirements.

It is noted that construction of the water and gas pipelines, the Fifield bypass and SR64 upgrade will be the subject of separate construction management plans. The construction management plans for the pipelines will deal with special traffic management measures to be implemented where these cross roads. They are to be prepared prior to construction in consultation with local councils and the RTA. Accordingly these aspects of the proposal are not dealt with any further in this report.

Finally it is understood that as a separate exercise Lachlan Council proposes to improve two sharp bends on SR60 and has plans to further upgrade the road progressively in the future. This will be the preferred route from Condobolin to the mine.

Access to the mine site is proposed off Shire Road 34 (Fifield – Wilmatha Road). The mine access will intersect with SR34 at an AUSTROADS Type C intersection designed with geometry suitable for road train turning movements. Within the site it is proposed to provide a gatehouse to control public access about 70 metres from the access intersection. A car park with about 150 parking spaces is proposed for staff and visitors. This will have geometry in accordance with Australian Standard AS2890.1 – Off Street Car Parking.

4. Operational Transport Demands

4.1 Transport of Raw Materials and Product

Attachment C of this report provides a schedule of raw materials and product that will be transported to and from the site.

The methods of transporting these plus plant and equipment are summarised below and then discussed in more detail thereafter.

- Sulphur – by rail from Newcastle. In the start up period sulphuric acid rather than sulphur would be transported from Newcastle by truck
- Water – by pipeline
- Natural gas – by pipeline
- Caustic soda – by rail or road from Sydney (assumed rail for modelling purposes)
- Magnesia – by road from Young
- Limestone – by road from limestone quarry near Trundle
- Miscellaneous raw materials – by rail from Newcastle
- Fuel – by road from Parkes/Sydney
- Miscellaneous supplies and equipment – by road from various sources
- Product – by rail to Newcastle

It is proposed that transport of materials and product to/from the site be handled by transport contractors. Contractual obligations will require heavy vehicles to use the nominated heavy vehicle routes as well as comply with standard RTA requirements such as the covering of loads etc. Heavy vehicles must also comply with Council wet road closure regulations. Breach of the contract will result in fines, payment of damages and possible dismissal.

Sulphur
Sulphur will be shipped from sources overseas to Newcastle where it will be offloaded and stored in an existing weather protected bulk stockpile. Typical shipments will be 20,000 to 50,000 tonnes. Transport to the mine will be via a dedicated train that will typically make two round trips per week to the proposed new rail siding north of Trundle.

Each train is proposed to have 44 wagons, 39 of these will each carry two purpose built special 6m long tipper containers. The other five will carry conventional containers in which miscellaneous materials will be transported. The containers will have 24 tonne capacities so each train will carry about 1872 tonnes of sulphur. Sulphur will be loaded into the containers using front end loaders.

As indicated above, to avoid congestion in the Sydney rail network as well as steep grades in the crossing of the Blue Mountains, the project’s rail service and logistics suppliers propose that trains to and from the site use a route via Muswellbrook, Ulan, Dubbo, Narromine and Parkes to Bogan Gate.

The new Syerston mine siding is proposed to be long enough for half of a train from Newcastle. Most of the year the branch line is largely unused and at these times trains will be broken into two with one half stored on the branch line while the other half is in the siding. The two halves would then be switched around as necessary.

At times when the branch line was in use (e.g. during wheat harvesting times), the half train not positioned in the siding would instead be temporarily held in the Troffs siding or could be stored at Bogan Gate or Parkes (although this is unlikely to be necessary).

Containers will be offloaded from the train by forklift and placed into a temporary storage area. From this they will be loaded progressively onto a shuttle fleet of road train truck rigs each of which will transport the two containers to the mine site via Shire Road 64 (SR64) and the proposed Fifield Bypass where they will be unloaded. Each trailer will carry one container.

A fleet of five truck rigs is proposed including one B-double combination and four road train combinations. These will also carry limestone to the mine as described below. Transport of the total annual load of 210,000 tonnes of sulphur from Newcastle will require on average about 12 deliveries per day. However on some days the truck fleet will carry only sulphur and on other days only limestone so the actual number will vary considerably from day to day.

Caustic Soda

Caustic soda is proposed to be transported in containers, by rail or road, probably from Sydney. For the purpose of this study transport by rail was assumed. It is proposed that the containers be attached to an interstate train for transport to Parkes. From Parkes these wagons would be pulled to the new siding by a contract locomotive. The wagons from each consignment plus the locomotive would all fit in the new siding.

Caustic soda containers would be offloaded by forklifts and trucked to the mine in the same way as sulphur. Transport of the annual load of 10,000 tonnes of caustic soda will require on average about 1 delivery every two days.

Magnesia

Magnesia would probably be sourced from Young. It is proposed to transport this by road in a bulk pressure tanker B-double truck that will make two round trips per day. The route to be followed will be Young, Grenfell, Forbes, Parkes, Bogan Gate, Trundle and the reverse. Typically there will be ten round trips per week. Normally these would occur on weekdays but weekend transport would occur as necessary.

Limestone

Limestone will be transported from the quarry to the mine using the same road trains that will be used for sulphur transport. Each trailer will have a side tipping container with 24 tonne capacity. Thus each trip will carry 48 tonnes of limestone.

Road train combinations will operate two 12 hour shifts per day. Each round trip between the quarry and the mine will take 1 hour and ten minutes. Thus there would be a maximum of 9 two way vehicle movements per hour on SR64 between the quarry and the mine. On average there will be about 36 limestone deliveries per day but there would be less when sulphur was being transported and more when it was not.

Fuel and Lubricants

Fuel will be transported by 19m B-double tankers from Sydney or smaller tankers from Parkes. Lubricants will be sourced from Parkes. It is assumed that there will typically be about three such deliveries per week.

Miscellaneous Bulk Materials

It is proposed that miscellaneous bulk materials be transported to Newcastle and carried to the mine in containers on the sulphur transport trains. The transport of these materials will require on average 2 deliveries per day.

Other Materials and Equipment

These include special equipment and supplies. Supplies and equipment will come from local sources and from Sydney. It is anticipated that there will be around ten of these deliveries per day. In addition to this it is expected that there would likely be around ten further light truck and van visits to the site per day relating to maintenance and on-going minor development works. These would also have local origins.

Mine Product

Approximately 25,000 tpa of nickel and cobalt (or 42,000 tpa of nickel cobalt sulphide precipitate) will be produced, mostly for export. This will be transported to Newcastle by backloading containers bringing sulphur to the mine. Thus delivery of product will involve no extra road or rail movements.

Table 4.1 – Summary of Materials Movement

Product	**Average Daily Truck Movements To or From**					**Train Movements on Branch Line Per Week**
	Rail Siding	**Limestone Quarry**	**Young**	**Local Sources**	**Sydney**	
Sulphur	24					4
Caustic Soda	1					2
Magnesia			4			
Limestone		72				
Misc Bulk	4					
Other				40	4	
Fuel/Lubricants				1		
Mine Product*						

Note: Each return trip = two movements, average daily movements are shown
* Backloaded on general goods trains

There would be typically 6 train movements per week on the rail branch line from Bogan Gate to the mine siding. Usually there would be no more than two rail movements per day – one each way. The Rail Access Corporation has advised that there is adequate line capacity to accommodate this level of rail usage.

4.2 Employee Traffic

Employee traffic on roads leading to and from the mine will be determined by the distribution of employee residences, the number that attend work each day and the proportion that drive cars.

It is expected that administration employees will typically work a five day week while miners and process employees will work a combination of five days out of any seven during the week or four days on/four days off with 12 hour shifts. Expected typical attendance on a weekday is 183 persons. To allow for periods when training took place or for above average activity periods this assessment has been conducted on the basis of 200 staff being present on a particular day. Shift start and finish times are consistent with the Cadia Gold Mine at Orange which employs a similar number of staff and operates under a similar staff roster. The following nominal shifts are expected to operate on a weekday.

Table 4.2 – Indicative Shift Start and Finish Times and Employee Numbers

Start	Employees In	Finish	Employees Out
6:00	33	6:00	10
6:30	1	7:00	27
7:00	127	15:00	14
7:30	1	15:30	1
8:30	1	16:30	15
18:00	10	17:00	10
19:00	27	17:30	1
		18:00	27
		18:30	8
		19:00	87
Total	200		200

For the Cadia mine it was found that typical day shift employees travelled with an average of 1.4 persons per car while night shift persons travelled with 1.2 persons per car. It was also found that the daily work routine did not adhere strictly to nominal shift times. Using this information, the estimated employee traffic generation of the Syerston Project is as set out on Table 4.3.

Table 4.3 – Estimated Daily Employee Traffic Generation

Hour Commencing	Vehicles In	Vehicles Out
5:00	24	
6:00	66	9
7:00	20	20
8:00	5	2
15:00		11
16:00		11
17:00	9	8
18:00	20	24
19:00	3	61
20:00		1
Total	147	147

Employee homes are expected to be distributed in accordance with the prevailing distribution of population in the vicinity of the mine. The estimated employee distribution and consequential distribution of daily and peak hour employee traffic leading to and from these locations is set out on Table 4.4.

Table 4.4 – Expected Distribution of Employees and Their Traffic

Location	Estimated Percent of Employee Homes[2]	Employee Vehicles Travelling To and From Location		
		Weekday vehicles/day[1]	Peak Hour (vehicles/hour)	
			AM	PM
Parkes	65.5%	192	49	41
Trundle	2.5%	8	2	2
Tullamore	2.0%	6	1	1
Condobolin	29.0%	84	21	18
Bogan Gate	0.5%	2	1	1
Ootha	0.5%	2	1	1
Total		294	75	64

(1) Adjusted to achieve even numbers as each car visit from home to work and back represents two vehicle trips.

(2) The distribution of employee residences has been estimated according to the population size of existing centres (ie. larger centres are expected to attract a higher proportion of the proposed workforce).

4.3 Other Mine Traffic

Other traffic visiting the mine during its operational phase will include daily consumables, locally sourced spare parts and equipment, maintenance contractors, mine staff visiting off-site facilities, regulating inspectors and general visitors.

For the Cadia mine non employee traffic amounted to a further 150 vehicle trips per day (75 visits) of which half were trucks. The amount of such extra traffic would be lower for the subject proposal because some equipment and materials will be transported by rail and because of the greater remoteness of the site. For assessment purposes it is considered reasonable to allow a further 100 vehicle movements per day with these being oriented 90 percent towards Parkes and 10 percent towards Condobolin. This traffic would occur mainly between 7:00am and 6:00pm with peak hourly traffic volumes being increased by perhaps 10 vehicle movements per hour.

It is unlikely that there will significant traffic volumes travelling between Syerston and the North Parkes Mine. Deliveries of materials to Syerston will be bulk consignments which will be entire truck loads and it is unlikely that there will be many contractors who serve both mines.

Traffic associated with maintenance of the gas and water pipelines during the operational phase of the mine is expected to be minimal. Traffic during construction of these pipelines will be managed in accordance with the relevant construction management plans.

4.4 Future Traffic Flows on Roads in The Area

In total the operational traffic generation of the mine is forecast to be about 550 vehicle movements per day made up as follows:

- about 300 employee vehicle movements per day
- about 150 truck and van raw materials transport vehicle movements per day
- about 100 other vehicle movements per day.

Out of interest it is noted that Parkes Shire Council has counted around 515 vehicles per day on Bogan Road south of the North Parkes mine and about 85 vehicle movements per day on Bogan Road north of the North Parkes mine. The North Parkes mine has around 280 staff on site at any one time.

This confirms the order of traffic estimate for the subject proposal.

Table 4.5 adds additional traffic estimated above to existing traffic levels on different roads to provide an estimate of likely future traffic levels when the mine is fully operational.

Table 4.5 – Existing and Future Daily Traffic Volumes on Affected Roads

Road	Location	Existing Daily Traffic Volume (vehicles/day)		Future Daily Traffic Volume (vehicles/day)		Existing Quality of Service	Future Quality of Service
		Total	Heavy(1)	Total	Heavy		
State Rd 90	E of Bogan Gate	792	95	887	190	Good	Good
MR350	Bogan Gate to Trundle	388	47	485	142	Good	Good
MR350	N of Trundle	339	41	685	136	Good	Good
SR83	E of MR350	99	12	340	12	Fair/Good(2)	Poor/Good(2)
SR64	E of MR57 Nth	52	9	499	205	Good	Good(3)
Fifield Bypass	E of MR57 Nth	-	-	449	196	-	Good(3)
MR57 Nth	N of State Rd 90	216	26	305	29	Good	Good
MR57 Nth	N of Fifield Bypass	63	9	65	9	Good	Good
SR44	E of SR60	90	11	179	14	Fair(4)	Poor(4)
SR34	S of SR44	90	11	179	14	Fair(4)	Poor(4)
SR60	N of MR57 Nth	90	11	179	14	Good	Good
MR57 Nth	S of Tullamore	164	20	170	20	Poor/Good(5)	Good

(1) Assumed at 12% of total when heavy vehicle count not available
(2) Fair/poor on gravel section, good on sealed section
(3) Assumes constructed with two lane seal as proposed.
(4) No traffic data available, assume similar volumes to SR60 for worst case
(5) Poor on gravel section, good on sealed section

Traffic travelling between Parkes and the subject site can travel from State Route 90 through Bogan Gate to MR350 or use Middle Trundle Road (SR83). The SR83 route is 10 kilometres shorter but has about 15 kilometres of unsealed road.

The use of SR83 by mine traffic will depend to a large extent on the condition of the unsealed section of it. With regular maintenance it would allow travel at around 80km/h and would thus be the quickest route between Parkes and the mine and as such it would be likely to attract most mine employee traffic. However after rain or if maintenance was deferred it would receive much lower usage.

This assessment uses the worst case scenario where all light traffic from Parkes uses SR83 between State Route 90 and the mine.

Heavy vehicles will be required to use the nominated route through Bogan Gate and the nominated heavy vehicle routes through Parkes. No heavy vehicles are expected to use any approach roads to the north during the operational phase of the mine.

Table 4.5 indicates that subject to the upgrading of the road between the proposed rail siding and the mine and construction of the Fifield bypass to appropriate standards, the quality of service on most roads serving the proposed mine will be satisfactory. Upgrading standards are discussed below in Chapter 4.5. The exceptions are SR83 (Middle Trundle

Road), SR 44 (Melrose – Gillenbine Road), and SR34 (Fifield – Wilmatha Road) which all have a future quality of service of 'poor' where the road is unsealed. That section of SR83 that is sealed will retain a 'Good' quality of service.

Table 4.6 presents estimates of future peak hourly traffic flows.

Table 4.6 – Existing and Future Peak Hourly Traffic Volumes on Affected Roads (vehicles/hour)

Road	**Location**	**Existing Peak Hour Flows**		**Future Peak Hour Flows**	
		AM	**PM**	**AM**	**PM**
State Rd 90	E of Bogan Gate	57	86	68	97
MR350	Bogan Gate to Trundle	28	42	40	54
MR350	N of Trundle	24	37	92	97
SR83	E of MR350	7	11	61	57
SR64	E of MR57 Nth	4	6	76	70
Fifield Bypass		-	-	72	64
MR57 Nth	N of State Route 90	16	24	39	44
MR57 Nth	N of Fifield Bypass	5	7	5	7
SR60	N of MR57 N	6	10	29	30
MR57 Nth	S of Tullamore	12	18	14	20

Future peak hour estimates provided on Table 4.6 are still low relative to the theoretical capacity of a two lane two way road which is 2,800 vehicles per hour. Comparison of these with the priority intersection control criteria on Table 2.5 indicates that no intersections in the area would need other than priority traffic controls.

4.5 Assessment of Road Improvement Needs

The assessment above indicates that the geometry of local road lengths on the route between the proposed rail siding and the mine will be adequate subject to the proposed upgrading of this route and construction of the Fifield Bypass. This route consists of a short section of MR350 between the rail siding access and SR64, SR64 itself, the new Fifield bypass, and the section of SR34 between the bypass and the mine access road.

It is understood that these have or will have no formal stock crossing requirements and that shoulders of the road will be widened to provide a 3m wide gravel shoulders at property accesses to allow a vehicle passing another turning right into a property to move around it on the shoulder or to allow vehicle turning left out of the road to move onto the shoulder out of the way of any closely following vehicle. The area on the shoulder at property accesses will also allow school buses to pick up and drop off school children clear of the carriageway. Representatives of Lachlan and Parkes Councils also recommended that the school bus on SR64 be fitted with a radio so that it can alert truck drivers to its presence on the bus route.

Given the proposed use of road trains on SR64 and the Fifield Bypass they should upgraded to the following standard:

- minimum lane width – 3.25m
- minimum sealed shoulder width – 1.0m
- minimum 3.0m gravel shoulder at property accesses
- minimum advisory speed for horizontal curves – 50km/h.

The 8.5m wide carriageway width has been nominated by Parkes Shire while the horizontal geometric requirement is from RTA requirements for road train routes. In addition to this, some intersections along the roads to and from Parkes and Condobolin will need to be upgraded to provide sheltered right turn bays and appropriate truck turning radii. Improvements at the following intersections are considered necessary:

- State Route 90/MR350 – AUSTROADS Type C intersection
- MR350/SR64 – AUSTROADS Type C intersection
- SR64/limestone quarry access Type C intersection
- SR64 with routes 361, 66, MR57 North – Type C with priority to SR64
- Fifield Bypass/MR57 North – Type C intersection
- Fifield Bypass/SR34 – Type C intersection
- State Route 90/MR57 North – Type C intersection
- SR60 (Springvale Road) MR57 North – Type B intersection if SR60 is retained as the cross of the tee intersection.

It has been recommended by the Traffic Sub-Committee that the route between the rail siding and the mine have priority at all intersections except at the intersection of MR350 and SR64. This will necessitate the realignment of the intersection of MR57 North and SR64 to make the south approach of MR57 North the stem of the T-intersection. The configuration of the intersection will need to be agreed with Councils and RTA during the detailed design phase.

Lighting should be provided at the intersections of MR350/SR64 and MR57 North/SR64. Appropriate signage complying with the relevant standards should also be provided at new and upgraded intersections.

Any other upgrading needs for SR60 have not been examined as part of this investigation as it is understood that this route is proposed to be progressively upgraded by Lachlan Shire Council (See Chapter 3). SR60 provides a better route between Condobolin and Fifield and with this upgraded it would be logical to transfer Main Road status from the parallel section of MR57 North to it. Additional traffic on SR44 and SR 34 will require their sealing between SR60 and the mine site.

The usage of SR83 (Middle Trundle Road) by light traffic associated with the mine will necessitate the sealing of some 15 kilometres which is currently unsealed. Heavy vehicles will be required to use the nominated route through Bogan Gate on State Route 90 and MR350. However, should the whole of SR83 be upgraded to a standard suitable for heavy vehicles some time in the future, the requirement that heavy vehicles associated with the mine travel through Bogan Gate would no longer be necessary. The removal of this requirement is a post-consent issue which can be finalised with Councils.

The RTA requested investigation of possible need for flashing lights and bells at railway level crossings. The need for these is given in the RTA Traffic Engineering Manual Section 6 – Railway Level Crossings (Draft) 1994.

During harvest season there can be up to 14 train movements per week on the Bogan Gate to Tottenham line. At other times the train movements on the branch line are minimal.

The subject proposal would increase trains by up to 6 movements per week. Therefore there could be up to 20 train movements per week at peak times.

The warrants are shown in Table 4.7 and require that the product of daily vehicles (V) and weekly train movements (T) at the crossing should not exceed 45,000.

Table 4.7 – Indicative Warrants for Signal Control Devices

Existing Installation	Multiple Tracks	Required Condition VT greater than	Warranted Installation
(i) Sign Control			
(a) Approach road speed of 60km/h	No	50,000	Type F Flashing Lights
	Yes	80,000	Type F Flashing Lights and half boom barriers
(b) Approach road speed of 100km/h	No	45,000	Type F Flashing Lights
	Yes	70,000	Type F Flashing Lights and half boom barriers
(ii) Type F Flashing Lights		1,000,000	Type F Flashing Lights and half boom barriers

On this basis with up to 20 train movements per week, daily traffic volumes would need to equal or exceed 2,250 vehicles per day at the level crossing. Table 4.5 indicates expected future daily traffic volumes on MR350 of 685 vehicles per day, State Route 90 of 887 vehicles per day. On this basis, flashing lights and bells are not required.

It is however recommended that during the development of road improvement designs for roads serving the mine that each of the level crossings be investigated to determine the possible need for minor safety improvements including sight distance improvements or the replacement of give way signs with stop signs.

4.6 Rail Interruption Contingency

As outlined above, it is proposed to transport all the sulphur and caustic soda required for the mine’s operation by rail to the proposed new rail siding. Approximately 10,000 tonnes of sulphur and 200m^3 of caustic soda will be stockpiled on site at any time before being used by the mine’s production facilities.

Should the rail transport of sulphur from Newcastle be interrupted due to problems on the rail network, the stockpile of sulphur provides for 17½ days of mine production and in addition there is 7 days acid storage and 2 days molten sulphur storage before alternative arrangements would have to be made.

Similarly, the stockpile of caustic soda on site will allow normal production to continue for 4-5 days should the rail service from Sydney be interrupted with a shortage only effecting the refinery operation.

In the unlikely event that the rail service from either Sydney or Newcastle was interrupted for a longer period, the mine operators would liaise with the RTA and local councils to identify acceptable routes and safety precautions for the road transport of sulphur and caustic soda.

5. Construction Transport Implications

5.1 Construction Workforce Traffic

It is proposed that the vast majority of the workforce live in a self-contained on site construction camp. A bus service is proposed to transport construction workers between Parkes airport and the camp.

It is understood that there is the possibility of a daily air service to Condobolin being operated in the future. Condobolin airport is located near the intersection of State Route 90 and SR60. Should this eventuate, a bus service could operate from Condobolin airport to the mine via SR60 and SR44 instead, as it is somewhat closer to the mine site than Parkes airport. However, the traffic assessment assumes that Parkes airport is the primary origin of the off site workforce.

In the first 7 months of the construction period, there will be relatively few people at the site. This time is allocated for general off-site activities such as detailed design, procurement of equipment/plant and other pre-construction activities. Once on site construction activities commence, the numbers of staff and contractors on site will increase significantly. Table 5.1 below provides a schedule of the average daily workforce during the construction phase of the project.

Table 5.1 – Schedule of Average Daily Workforce

Month	Average Daily Workforce (persons)	Month	Average Daily Workforce (persons)
7	426	16	802
8	478	17	593
9	629	18	710
10	585	19	674
11	628	20	638
12	604	21	572
13	714	22	421
14	962	23	359
15	918	24	300

The construction camp is proposed to be operational when on-site construction activities commence (ie. month 7 in Table 5.1). During operation of the construction camp the peak occupancy is expected to be 962 persons and the average about 540 persons.

It is proposed that buses operate as frequently as necessary between Parkes airport and the construction camp. The number of these will depend on flight schedules and the extent to which charter aircraft are utilised. It is expected that there will be at least one bus trip per day to and from the airport during most of the construction period.

It is difficult to know the extent to which construction workers will be drawn from the surrounding population and the extent to which non-local construction workers will prefer to live in casual accommodation in the surrounding district. Obviously the incidence of this will be limited by the availability of such accommodation.

On balance it is considered reasonable to assume that perhaps 10 percent of the construction workforce will live in accommodation in the surrounding area. This implies about 50 persons on average living in the surrounding area with about 100 at the peak.

Traffic generated by the construction workforce will include:

- travel by employees resident off camp
- recreational travel by employees resident in the camp
- bus trips to/from the airport
- delivery of food and other consumable supplies to the camp.

Indicative daily estimates of this traffic are set out in Table 5.2.

Table 5.2 – Estimate of Construction Workforce Traffic

	Average (vehicles/day)	Peak (vehicles/day)	Comment
Off camp employees	72	144	1.4 persons/vehicle
Recreational travel	34	68	3 persons/vehicle, 10% of camp go & return each day
Airport bus trip	2	4	
Camp deliveries	20	30	
Total	**128**	**246**	

Note: Each return trip = two movements

5.2 Major Equipment and Supplies

Based on a construction programming analysis the design team has estimated that these will peak at a monthly average of about 12 deliveries per day (24 vehicle trips per day). On average over the whole construction period it is expected that there will be about 6 or 7 major deliveries per day (12 to 14 vehicle trips per day).

5.3 Other Traffic

Other traffic generated during construction will include that due to visiting company, design and regulatory personnel, general equipment and consumables, local contractors, construction personnel moving to and from off site construction locations.

Again this traffic is difficult to estimate due to a high degree of variability during the construction process. A recent survey of traffic entering and leaving the Ridgeway gold mine site during construction of a trial mine found that this generated about 120 non-employee vehicle trips per day (45 trucks and 75 light vehicles). That project had a workforce of about 300 persons. For planning purposes it is considered appropriate to make the following indicative allowances for other construction traffic travelling to and from the main mine site:

- design, regulatory and general visitors to site – 35 to 50 trips/day
- consumables and general equipment – 35 to 50 trips/day
- trips between mine site and related off site construction areas (pipelines, siding) – 100 trips/day
- limestone quarry development – 50 trips per day
- railway siding development – 50 trips per day
- **Total** **270 to 300 trips per day**

It is noted that trips referred to are two way totals ie a visit to the mine generates two vehicle trips. About one third of these would be heavy vehicles.

Further traffic generated by construction by the gas and water pipelines and the borefields will for the most part focus on the route of these and not on the mine site itself. Traffic generation associated with these will relate to:

- construction vehicles (eg sideboom tractor)
- delivery of pipes, fittings, bores and associated equipment
- delivery of bedding material
- daily employee travel.

Separate contractors with their own work compounds will be responsible for these. Indicatively it is expected that these will total perhaps 50 vehicle trips per day each.

The routes of the proposed gas and water pipelines and the borefields are indicated on Figure 2. As mentioned previously these will each be subject to their own construction management plan which will deal with traffic effects separately.

The additive effect of traffic generated by these activities will be relatively small with the greatest impact being on Route 64 and the proposed Fifield Bypass which are to be upgraded to carry extra traffic anyway. Springvale Road (SR60) will also experience additional traffic while construction of the gas pipeline is undertaken along this road.

5.4 Total Construction Traffic

Table 5.3 provides an estimate of the total daily traffic generation of construction activities.

Table 5.3 – Combined Construction Traffic Estimate (vehicles/day)

	Average Period			Peak Period		
	Heavy	**Light**	**Total**	**Heavy**	**Light**	**Total**
Workforce	22	106	128	34	212	246
Major Equipment & Supplies	15	-	15	24	-	24
Other Traffic	90	180	270	100	200	300
Total (rounding)	130	290	420	160	420	580

Table 5.3 indicates an expectation that there would be a total of about 420 vehicle trips generated per day by the mine site on average throughout the construction period with some 580 vehicle trips per day during the peak construction month. By way of comparison a total traffic generation of the mine of about 550 vehicle trips per day is forecast for the operational phase.

Further construction activities will take place at the limestone quarry and railway siding site. These are each expected to involve a workforce of only about 15 to 20 persons and at this stage are expected to be undertaken separately at the following times:

- quarry: 3 months construction
- rail siding: 3 months construction

These could also generate up to about 50 vehicle trips per day. Some of these would be to and from the main mine site and have been allowed for above. The nett increase in traffic generation at any one time is expected to be about 30 vehicle trips per day at one or other but not both sites at once.

5.5 Implications of Construction Traffic

The construction traffic will be principally focussed on:

- Fifield Bypass and SR64 between the mine site and the Limestone quarry site and siding construction site
- MR350 plus State Road 90 to/from Parkes
- SR83 between State Route 90 and MR350

SR60 and MR57 North to/from Condobolin will be used to a lesser extent by any construction workforce living in Condobolin.

At the peak of construction, traffic increases on State Route 90, MR 350, SR83, SR64, and MR57 North to and from Parkes and Condobolin would be comparable to those estimated above for the operational phase of the mine. Traffic volumes on the Fifield Bypass and SR64 between the mine and MR350 would be lower as there would not be sulphur or limestone deliveries between the rail siding/quarry and the mine.

The overall implication of construction traffic volumes is that no additional road improvements will be required but that those needed for the operational phase should be made prior to commencement of operation of the construction camp.

Construction of the water and gas pipelines, the Fifield bypass and SR64 upgrade will be the subject of separate construction management plans. The construction management plans for the pipelines will deal with special traffic management measures to be implemented where these cross roads. They are to be prepared prior to construction in consultation with local councils and the RTA.

5.6 Oversize Vehicles

Oversize vehicles will be used to transport some of the plant equipment to the site from major cities such as Sydney and Adelaide. Each will be subject to a special permit from the RTA and timing, routes and any special preparatory measures will be agreed with the RTA and local councils involved beforehand.

5.7 Mine Start Up Phase

Towards the end of the construction period it will be necessary to bring in initial quantities of raw materials to build up stockpiles and allow the processing plant to be commissioned.

On site processing of ore will involve the use of sulphuric acid which is to be made on site from the imported sulphur. Whilst the plant is being commissioned it will be necessary to import sulphuric acid in B-double tanker trucks from Newcastle. Over a six month period, between 12 and 28 deliveries will be required per day ie 24 to 56 vehicle movements per day.

The trucks would travel from Newcastle to Dubbo on the Golden Highway. From Dubbo, they would travel northwest through Narromine to Trangie, southwest to Albert and then southeast on MR350. All these routes are approved B-double routes.

As for heavy vehicles during the operational phase of the mine, contractual obligations will require heavy vehicles delivering sulphuric acid from Newcastle to use the nominated heavy vehicle routes as well as comply with standard RTA requirements. Heavy vehicles must also comply with Council wet road closure regulations. Black Range Minerals have advised that breach of the contract will result in fines, payment of damages and possible dismissal. MR354 between Narromine and Tullamore is not on the nominated route nor is it an approved B-double route. Heavy vehicles associated with the mine would not be allowed to use this road.

The truck movements would occur over months 1 to 6 in the first year of operation. They would thus not overlap with construction traffic and would occur before operational traffic had ramped up to its normal levels.

Subject to normal safety precautions for such loads this temporary transport task will not necessitate any additional road improvements.

6. Summary and Conclusions

6.1 Summary

The Proposal

- It is proposed to develop a nickel – cobalt mine at Fifield in Lachlan Shire.
- The location of the site and the roads serving it are shown on Figure 2 of this report.
- 371 persons are expected to work at the mine during the operational phase and approximately 25,000 tpa of nickel and cobalt or 42,000 tonnes of nickel cobalt sulphide precipitate is expected to be produced per annum.
- On site processing of mined ore is proposed.
- Principal raw materials and product are proposed to be transported by rail to/from Newcastle and Sydney and then by truck to the mine site and also by truck from a nearby limestone quarry.
- A new railway siding is proposed to be constructed for loading and unloading trains.

The following are the key findings of this investigation.

Existing Transport System

- Arterial road access to the region is provided by State Route 90 which connects Parkes to Condobolin. This has a two lane sealed carriageway in generally good condition.
- The main route to the mine will be via Main Road 350 which runs from State Route 90 at Bogan Gate to Tullamore via Trundle and thence Shire Route 64 to Fifield.
- Main Road 350 has a two lane sealed carriageway in generally good condition. However it has three level crossings over the Bogan Gate to Tottenham railway which runs parallel to it.
- Shire Road 83 provides a shorter route to Trundle off State Route 90 from the east, however, only part of it is sealed.
- Shire Road 64 between MR350 and Fifield has only a single lane sealed carriageway.
- Condobolin is the nearest town to the mine. Access between it and the mine site is provided by Main Road 57 North (MR57 north) via Shire Route 60 (Springfield Road).
- Traffic volumes on all of these roads are currently low (see Tables 2.1 and 2.2 in Chapter 2) and the roads which are sealed in the vicinity of the mine site and the principal ones leading to and from it presently exhibit ‘Good’ operating conditions. Those roads which are unsealed presently exhibit ‘Fair’ or ‘Poor’ operating conditions.
- Intersections in the area all operate satisfactorily under priority controls.
- Parkes is connected to Sydney by a heavy gauge railway line that crosses the Blue Mountains and to Newcastle by a heavy gauge railway that passes through Dubbo and the Hunter Valley.
- Rail Access Corporation has indicated that the line through the Blue Mountains and the Sydney Metropolitan area has only limited available train paths with goods trains only passing outside of peak commuter hours.

Transport Demands Generation

- At full operation the mine is expected to generate about 550 vehicle movements per day made up as follows:
  - About 300 employee vehicle movements per day
  - about 150 truck and van raw material transport vehicle movements per day
  - about 100 other vehicle movements per day
- During construction the traffic generation of the mine will be variable. It is expected to average about 420 vehicle movements per day but increase to about 580 vehicle movements per day during the peak month of construction.
- Construction of water and gas pipelines to the mine site are indicatively expected to generate a further 50 vehicle movements per day each. The focus of these will vary depending on which part of the pipeline was under construction at the time.
- About six train movements (three each way) are expected to be generated on the Bogan Gate to Tottenham branch railway line each week.
- The rail line through Dubbo and the Hunter Valley will be used for the transport of all bulk materials by rail from Newcastle. The line through the Blue Mountains will only be used for the transport of caustic soda from Sydney.

Implications of Rail transport

- There is adequate capacity on the railway lines serving the area to accommodate the rail traffic that will be generated by the mine.
- Use of rail will result in a significant reduction in the number of heavy trucks that would otherwise be generated by the mine.

Implications of Road Transport

- As part of the project it is proposed to construct a new road bypass around the south western side of Fifield.
- It is also proposed to upgrade SR64 from the Fifield Bypass to MR350 where the new railway siding is to be constructed. These improvements will satisfactorily cater for the main trucking movements to and from the site.
- The route between the rail siding and the mine will have priority at all intersections except the intersection of MR350/SR64. The intersection of MR57 North and SR64 will need be realigned to make the south approach of MR57 North the stem of the T-intersection. The configuration of this intersection will need to be agreed with Councils and RTA in the detailed design phase.
- Lighting at the intersections of MR350/SR64 and MR57 North/SR64 is required and appropriate signage should be installed at new and upgraded intersections.
- On MR350 it will be necessary to improve intersections at SR64 and at State Route 60.
- Comparison against formal warrants for different types of controls indicates that existing sign only controls at railway level crossings on MR350 are sufficient.
- It is however recommended that the possible need for minor safety improvements be checked at each.
- Subject to this, MR350 will be able to satisfactorily cater for the mine generated traffic.
- SR83 would be likely to attract a large amount of light traffic between Parkes and the mine which would necessitate its sealing. Consultation between the Traffic Sub-Committee members is proposed.

- Lachlan Council proposes as a separate exercise to upgrade Shire Road 60 to replace MR57 North as the principal road route between Condobolin and the mine.
- Shire Road 44 (Melrose – Gillenbine Road) and Shire Road 34 (Fifield – Wilmatha Road) will need to be upgraded at the same time as SR60. The objective would be to then transfer Main Road status from MR57 North to SR60.
- Extra traffic on this route due to the mine is not expected to be high but improved access between Condobolin and the mine would benefit both.
- Aside from the improvements mentioned above, intersections that will be subject to increased turning movements will need to be upgraded to provide sheltered right turn lanes, left turn deceleration lanes and improved left turn radii where appropriate.
- Subject to the improvements mentioned it is considered that the road system would be able to satisfactorily accommodate the generated traffic.

6.2 Conclusions

It is concluded that transport provisions for the proposed mine have been well planned through the proposed use of rail and the proposed substantial upgrading of the route between the mine and the proposed new rail siding.

To ensure satisfactory operation of the road system the following recommendations for additional improvement are made:

- conduct investigations to determine the possible need for minor safety improvements at railway level crossings on State Route 90, MR350 and the access road to the proposed siding and implement as appropriate
- provide AUSTROADS Type C intersection upgrades at the following intersections:
    - State Route 90/MR350
    - MR350/SR64
    - SR64/limestone quarry access
    - SR64/SR361
    - SR64/SR66
    - SR64/MR57 North with priority to SR64
    - Fifield Bypass/MR57 North
    - Fifield Bypass/SR34
    - SR34/Mine access road
    - State Route 90/MR57 North
- provide 3m wide shoulders for about 30m on each side of MR350 and SR64 at all minor side roads and property accesses
- provide AUSTROADS Type B intersection treatment at the intersection of SR60 with MR57 North
- provide lighting at the intersections of MR350/SR64 and MR 57 North/SR64
- provide appropriate signage at new and upgraded intersections.

Lachlan Council proposes as a separate exercise to progressively upgrade sections of Shire Road 60. This will replace MR57 North as the principal road route between Condobolin and the mine.

Shire Road 44 (Melrose – Gillenbine Road) and Shire Road 34 (Fifield – Wilmatha Road) will need to be bitumen sealed at the same time.

Additional traffic from the mine will necessitate sealing Shire Road 83 over its full length which would make it the principal light traffic route between Parkes to the mine via Trundle. Heavy vehicles associated with the mine will be required to use the nominated route through Bogan Gate. Should the whole of SR83 be upgraded to a standard suitable for heavy vehicles some time in the future, the requirement that heavy vehicles associated with the mine travel through Bogan Gate would no longer be necessary.

7. References

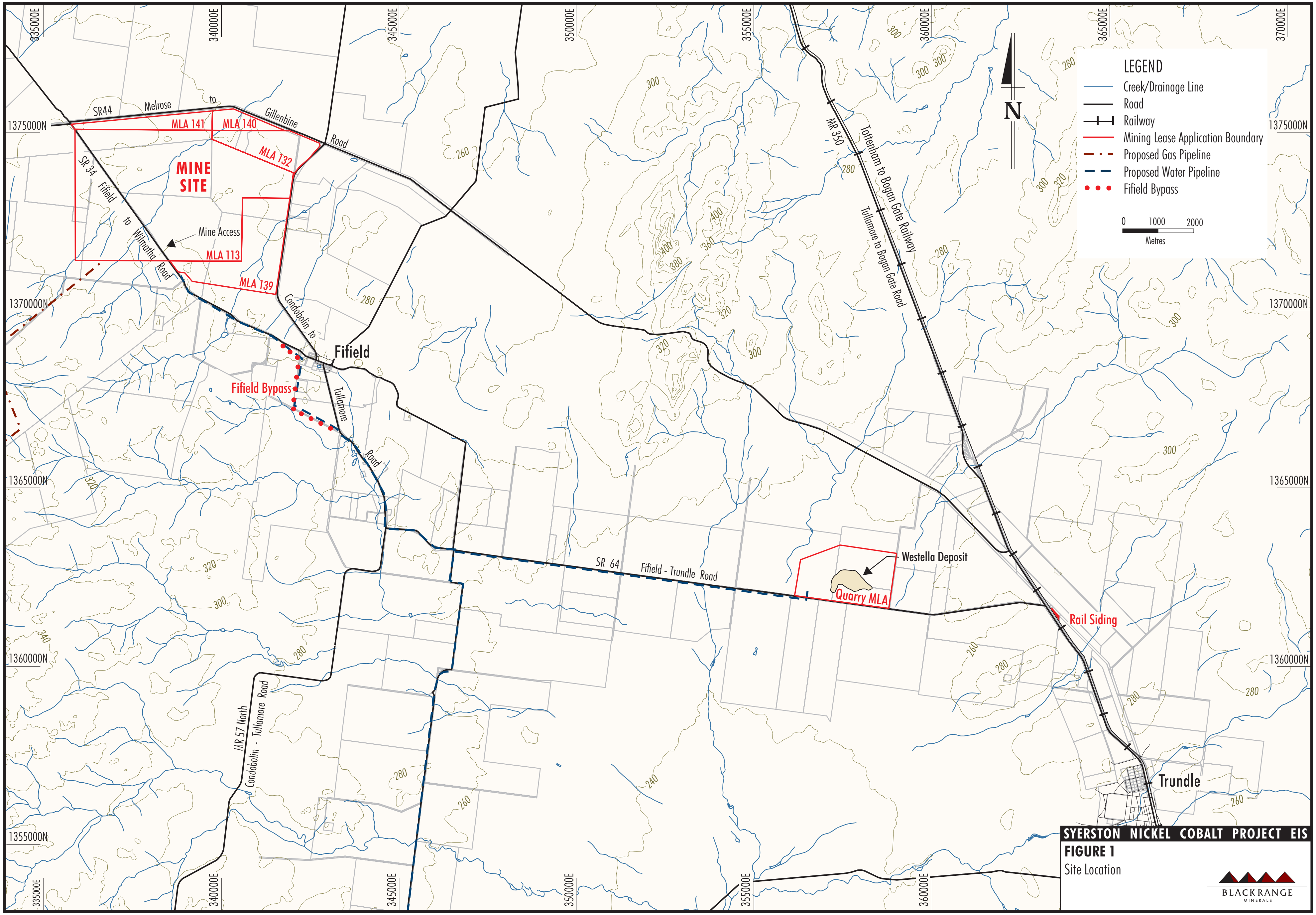
AUSTROADS (1998), *Guide to Traffic Engineering Practice, Part 2 – Roadway Capacity*, Sydney.

AUSTROADS (1998), *Guide to Traffic Engineering Practice, Part 5 – Intersections at Grade,* Sydney.

NAASRA (1984), *NAASRA Roads Study – Rural Arterial Roads Report, Study Report R1.*

Roads and Traffic Authority of New South Wales (1994), *Traffic Engineering Manual, Part 6 – Railway Level Crossings*, Sydney.

FIGURES



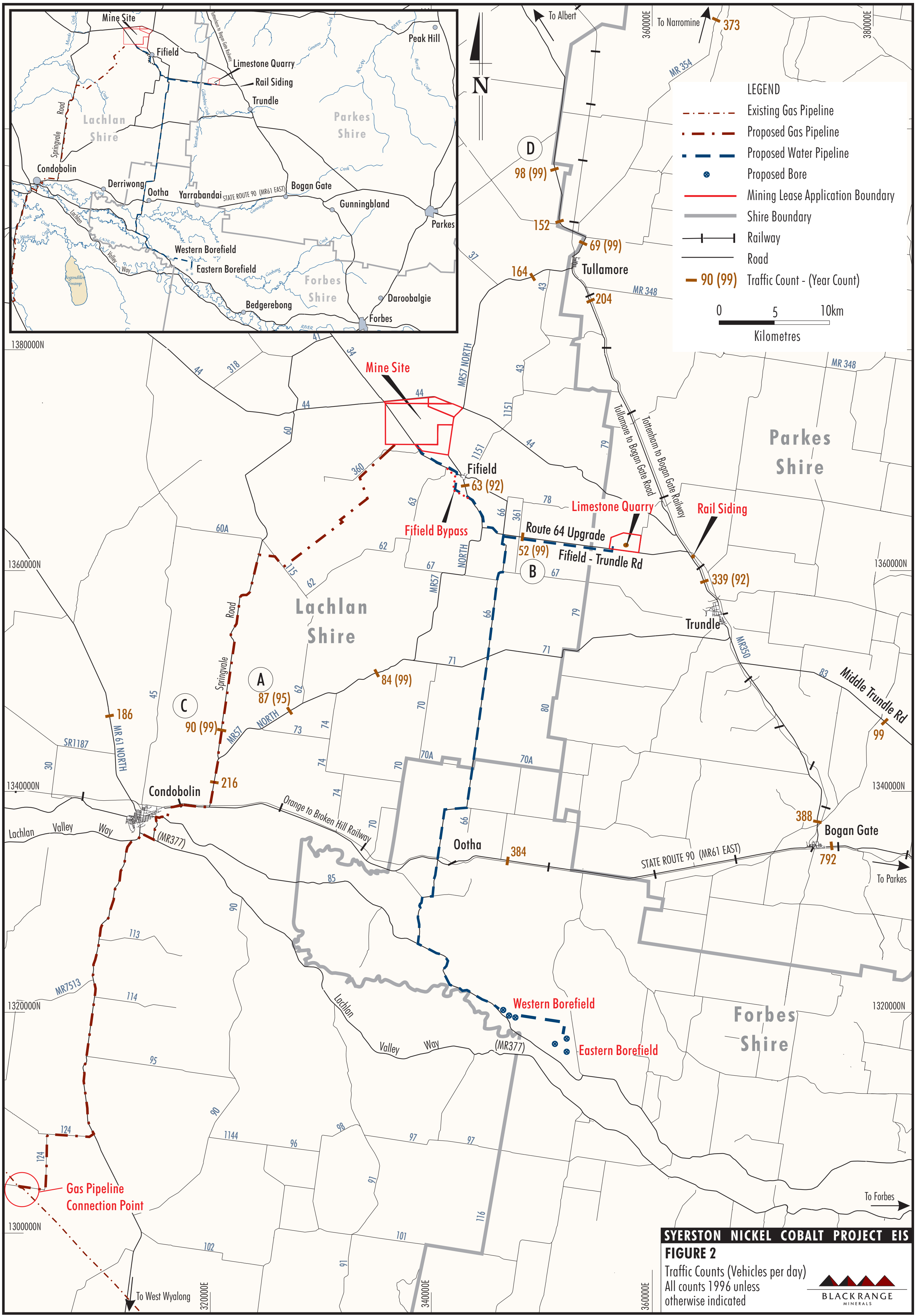
SYERSTON NICKEL COBALT PROJECT EIS

FIGURE 1

Site Location

BLACKRANGE MINERALS

BRM-98-01-Traffic_001C

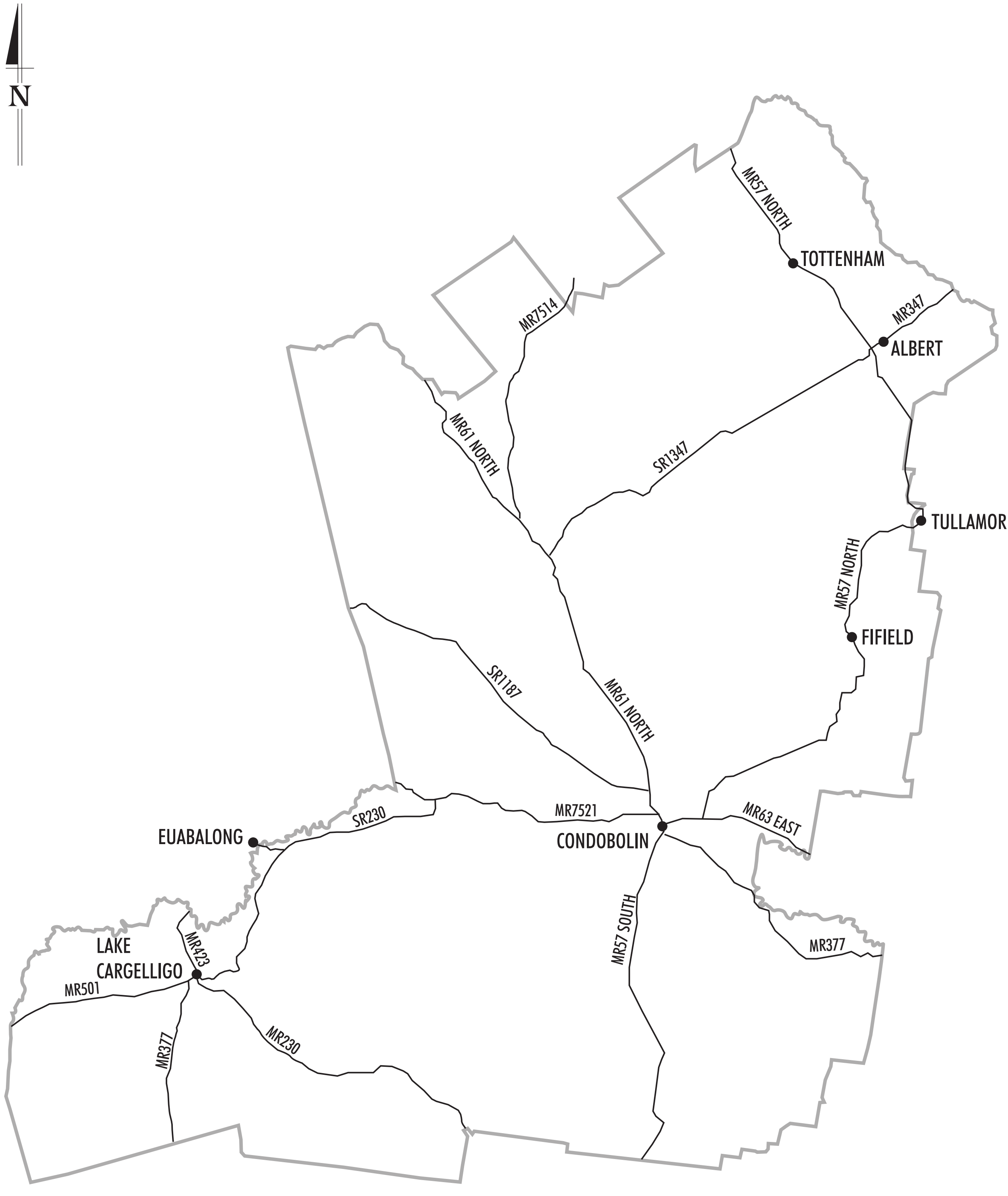


SYERSTON NICKEL COBALT PROJECT EIS

FIGURE 2

Traffic Counts (Vehicles per day)
All counts 1996 unless
otherwise indicated

BLACK RANGE MINERALS



SYERSTON NICKEL COBALT PROJECT EIS

FIGURE 3

Lachlan Shire
Main Heavy Vehicle
Transport Routes

Attachment A - Director's Requirements For Transport Investigation

Attachment B - AUSTROADS Intersection Types

Attachment C - Schedule of Raw Material and Product Quantities

APPENDIX D

SYERSTON NICKEL COBALT PROJECT

TAILINGS AND SITE WATER MANAGEMENT

PREPARED BY
GOLDER ASSOCIATES PTY LTD

AUGUST 2000
Project No. BRM-01\3.16
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1 INTRODUCTION

This Appendix presents the results of geotechnical, hydrological and hydrogeological studies conducted by Golder Associates Pty Ltd (Golder), in relation to the proposed development of mine infrastructure for the Syerston Nickel Cobalt Project (Syerston Project), near Fifield, central New South Wales (NSW) (Figure 1).

Black Range Minerals (BRM) is proposing to mine an average of 2 million tonnes per annum (Mtpa) of nickel laterite ore and establish a nickel and cobalt extraction plant at Syerston, 45 km north-east of Condobolin and 80 km north-west of Parkes in the central west of New South Wales.

An average of approximately 20,000 tpa of metal or up to 42,000 tpa of mixed nickel-cobalt sulphide precipitate products would be produced for sale to international markets. Annual metals production would peak at approximately 20,000 tonnes of nickel and 5,000 tonnes of cobalt.

An Environmental Impact Statement (EIS) for the proposed Project is required under the NSW Environmental Planning and Assessment Act (1979). The Project has mineral resources adequate for a mine life of over thirty years. In accordance with regulatory requirements, the EIS assesses the potential environmental impacts of the Project for a term of 21 years.

This Appendix is a summary of seven reports prepared by Golder for Black Range Minerals Ltd (BRM), *viz:*

(i) Regional and Local Hydrogeological Impacts of the Proposed Syerston Nickel Mine Fifield, NSW (Golder, 2000a).

(ii) Geotechnical Investigation for the Tailings Storage Facilities - Syerston Nickel Project (Golder, 2000b).

(iii) Surface Water Hydrology and Diversion Works - Syerston Nickel Project Fifield, New South Wales (Golder, 2000c).

(iv) Geotechnical Investigation for the Plant Site, Mine Pits and Limestone Quarry - Syerston Nickel Project Fifield, New South Wales (Golder, 2000d).

(v) Tailings Storage Water Balance - Syerston Nickel Project Fifield, New South Wales (Golder, 2000e).

(vi) The Preliminary Design of the Tailings Disposal Facility for the Syerston Nickel Project (Golder, 2000f).

(vii) Hydrogeological Impacts of the Tailings Storage Facility of the Proposed Syerston Nickel Mine Fifield, NSW (Golder, 2000g).

The work conducted as part of these studies included:

- Geotechnical investigations for the proposed process plant, tailings storage facility (TSF), evaporation ponds, mine pit walls and limestone quarry.
- Design of surface water diversion and process water management structures.
- Development of TSF and evaporation pond system water balance.
- Modelling of the potential hydrogeological impacts of the Syerston Project.

2 PROJECT INFRASTRUCTURE

The Syerston Project site (hereafter referred to as 'the site') is set in rolling, semi-cleared terrain just north-west of the small township of Fifield. The area is mixed grazing and cropping lands near the western edge of the NSW wheat belt. The site is predominantly cleared, gently to moderately sloping grazing land in the upper headwaters of Bullock Creek, which drains north to the Bogan River. The north-western corner has previously been worked for magnesite, with numerous spoil piles and shallow pits still evident.

Figure 2 shows a general arrangement of the proposed infrastructure items (relevant to the scope of this Appendix) to be developed for the Syerston Project, including:

- Open pit excavations.
- Process plant and associated infrastructure/services.
- TSF divided into northern and southern cells.
- Evaporation ponds 1 to 7.
- Evaporation surge dam, comprising four separate evaporation ponds.
- Surface water diversions and water management structures.

Presented below is a brief description of these infrastructure items.

2.1 MINE PITS

The Syerston Project would involve the development of 11 relatively shallow open pits in the first 5 years of operation (Figure 2). Thereafter, the open pits would be expanded and amalgamated to form a total of two pits by the end of the Project life. The pits would be mined in a sequence to meet the process plant production requirements. Each open pit would be excavated in shallow benches and stepped in accordance with slope stability requirements described in Golder (2000d). The perimeter of the pits would be bunded to prevent the ingress of surface water. Any rainfall runoff that accumulates within the pits would be pumped to small holding dams for use as dust suppression water across the mine site.

2.2 WASTE DUMPS

Waste rock generated during the life of the Syerston Project would be placed in strategically located waste dumps, built in layers to final height. Waste dumps would be advanced in benches and progressively rehabilitated as areas are completed. All runoff from the waste dumps would be collected in settlement dams. This water would be used for dust suppression across the site.

2.3 PROCESS PLANT AREA

The proposed process plant would be located on a constructed platform approximately 1,000 m by 600 m wide (Figure 3). The process plant would have an ore throughput rate of approximately 2 Mtpa. Any runoff from within the process plant area would be captured in runoff dams and sumps, and recycled through the process plant or pumped to the TSF.

2.4 TAILINGS STORAGE FACILITY

Tailings generated in the process plant are to be stored in a TSF located immediately to the south-east of the process plant (Figure 3). The TSF would comprise two cells, with a total area of approximately 217 ha. The tailings would be pumped to the TSF as a slurry with a solids concentration[1] of approximately 48%. A conventional sub-aerial spigot deposition system would be used to distribute the tailings across the beach of each TSF cell. This method of tailings deposition involves the progressive peripheral discharge of tailings slurry around the storage, and results in thin layer beaching.

The initial starter embankments would be up to 11 m high, with the final height of the TSF cells predicted to be approximately 30 m at the end of their operational life of over 20 years. It is proposed to raise the outer embankments of the TSF cells using conventional upstream lifting techniques. The TSF starter embankments would be built to an acceptable engineering standard for the containment of tailings.

Upstream lifts would be constructed in 1.5 m high rises and would be constructed on top of the tailings, using tailings excavated from the adjacent beach. The external batter slope of the TSF embankment would not be more than 3:1. Each lift would be constructed when the tailings beach level reaches a height within 0.5 m of the crest of the embankment (Golder, 2000a).

The outer face of each embankment raise would be rehabilitated, using a cover layer of sub-soils and topsoils. After approximately 9 lifts, a step-in of approximately 9 m would be made to provide runoff control. The surface of the step-in would be revegetated when the next embankment raise is made.

An underdrain system would be constructed at the inner toe of the embankment to intercept seepage and control the level of the phreatic surface within the TSF cells. Water collected in the underdrains would be piped to sumps outside the perimeter of the TSF embankment. These sumps would be dewatered to the TSF or to the evaporation ponds. The base of the TSF would be lined with a 1 m thick layer of compacted in-situ clay material, engineered to achieve a permeability of less than 1×10^{-9} m/sec.

The tailings slurry would be deposited into the TSF cells through a series of spigots located around the perimeter of the storage, so that a decant pond of supernatant water is maintained centrally around the decant tower in each cell (Figure 3). Rainfall runoff would also collect in the decant ponds. The decant ponds would be maintained approximately 300 m in diameter with some fluctuations in size in response to rainfall. Excess supernatant water would be decanted over a control weir and through a buried pipeline into the evaporation ponds. Periodically the decant tower would be raised to keep it above the level of the rising tailings beach.

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[1] Solids Concentration: Ratio of mass of solids to total mass of solids plus liquor

2.5 EVAPORATION PONDS AND SURGE DAM

Decant water from the TSF cells would be stored in the evaporation ponds located to the east of the TSF (Figure 3). The predicted water quality of the TSF supernatant water indicates that it would not be suitable to reuse in the process plant. The evaporation ponds and evaporation surge dam have surface areas of approximately 121 ha and 56 ha respectively (Figure 2).

The evaporation ponds would consist of contour dams contained by 2.5 m high earth embankments, with internal clay cutoffs and a cutoff trench under the embankment to intercept shallow seepage. The base of the evaporation ponds would be cut level and then compacted to a depth of 1 m to achieve a permeability of no more than 1 x 10^{-9} m/sec.

The base of the surge dam would be terraced to form four evaporation ponds, which would be lined with a compacted in-situ clay liner with a permeability of no more than 1 x 10^{-9} m/sec.

Decant water leaving the TSF cells would be piped into a sump, from where it would be distributed to the various evaporation ponds. When the capacity of the evaporation ponds is reached, excess water would be directed to the evaporation surge dam. When the evaporation ponds have spare capacity, water would be pumped back from the evaporation surge dam (Figure 2).

2.6 SURFACE WATER DIVERSIONS

Several surface water diversions are required as part of the development of the Syerston Project. The purpose of the proposed diversions is to divert surface water flows around areas of disturbance and items of infrastructure.

Figure 2 shows the proposed permanent surface water diversions that would be required for the life of the Syerston Project, including:

- Northern Diversion – to divert surface water around the north-western cluster of open pits.
- Southern Diversion – to divert surface water around the eastern perimeter of the evaporation ponds.
- Surge Dam Diversion – to divert surface water around the surge dam storage area to minimise upslope inflows.

3 DESCRIPTION OF THE EXISTING ENVIRONMENT

3.1 CLIMATE

The nearest long-record daily rainfall station is station #50028 at Murrumbogie, located approximately 15 km south-east of the site. This rainfall station has 116 years of record. Inspection of this record and comparison with other local records suggests that the Murrumbogie record is reliable. Local rainfall gradients appear to be relatively low.

Two pan evaporimeters have been operated close to the site (both 40 km south-west), at the Condobolin Agricultural Research Station (#50052, 1973-date) and the Condobolin Soil Conservation Service office (#50102, 1970-85). These instruments have recorded significantly different evaporation with long term annual means of 1,959 mm and 1,570 mm respectively (2,017 mm and 1,546 mm for the record-overlap interval).

To develop a site specific record a broad-scale interpolation scheme[2] was utilised that yielded a long term mean for the site of 1,833 mm. The adopted annual mean is in close agreement with published evaporation contours (Bureau of Meteorology, 1989). This result is consistent with the regional pattern, which has pan evaporation increasing to the west and north (compare Parkes - 80 km SE, 1,570 mm; Naradahan - 140 km SW, 1,790 mm; Trangie - 90 km NE, 1,970 mm).

Table 1 presents a summary of the Murrumbogie rainfall record. The full record for this station is presented in Golder (2000c).

Table 1
Murrumbogie Rainfall Station – Summary of Record

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Maximum	298.6	227.2	212.1	317.4	164.2	114.6	116.0	137.2	120.9	175.9	197.6	216.3	971
90 percentile	116.3	121.8	116.5	79.6	83.4	76.1	70.6	67.7	64.5	88.2	83.5	105.4	742
75 percentile	68.9	55.2	49.0	48.9	57.1	55.1	51.4	52.2	43.5	55.0	55.3	61.7	582
Mean	**51.0**	**43.4**	**41.2**	**37.0**	**39.3**	**38.8**	**36.0**	**37.0**	**32.5**	**42.0**	**37.7**	**43.7**	**480**
Median	34.3	23.0	25.3	22.6	33.5	32.9	30.6	32.1	26.9	32.2	25.7	32.2	465
25 percentile	13.6	7.2	10.5	9.5	15.3	17.6	17.8	16.4	14.8	16.9	11.6	11.5	331
10 percentile	4.3	3.8	0.2	1.4	5.1	11.5	6.5	7.9	7.8	9.7	2.0	3.9	282
Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0	0.0	0.0	166
Years of data	115	114	115	115	115	113	113	114	115	115	114	115	109

Table 2 presents the interpolated pan evaporation data developed for the Syerston Project site.

Table 2
Interpolated Pan Evaporation

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean	**275.7**	**226.6**	**195.3**	**120.1**	**69.5**	**45.2**	**50.6**	**74.2**	**108.3**	**168.5**	**219.4**	**279.5**	**1833**
Median	274.4	234.8	194.6	121.0	70.6	44.2	49.6	73.2	104.8	172.4	217.6	275.8	1863
Years of data	30	30	30	30	30	30	30	29	29	29	29	29	29

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[2] The Queensland DPI ‘Data Drill’.

Data presented in Tables 1 & 2 indicates a relatively dry (borderline semi-arid) climate. Rainfall is evenly distributed through the year, with a very slight summer maximum and significantly higher summer rainfall variability. There is a large annual excess of evaporation over rainfall (1353 mm).

The winter months have the highest soil moisture levels on average due to the markedly lower winter evaporation. Model-calculated[3] monthly total runoffs are, however, highest in January, reflecting the higher frequency of heavy, runoff producing, rainfall events in that month. Model-calculated long term runoff factors range from less than 10% for natural catchments to approximately 50% for 'hardened' but unsealed developed areas.

3.2 SURFACE WATER

The site is in the upper headwaters of Bullock Creek, which drains north to the Bogan River upstream of Nyngan. The local group of north-west-flowing rivers (Bogan, Macquarie, Castlereagh, Namoi and Barwon) drain a very extensive floodplain north of the site producing large areas of inundation in wet years.

Bullock Creek north of Tullamore (20 km north-east of the site, at approximately 250 m RL) flows at a relatively low gradient (approximately 1 in 1,000) across a topography indicative of significant flood inundation. However, gradients between Tullamore and the site are relatively steep. This indicates that a significant regional backwater effect is very unlikely due to the small upstream catchment.

The site is crossed by two ephemeral drainage lines, the northern and southern drainage lines, both running south-west to north-east (Figure 2). The northern drainage line divides within the site into its south and north branches.

3.3 GROUNDWATER

This section summarises the baseline hydrogeological conditions in the region and at the Project site, as reported in Golder (2000a, 2000g). Figure 4 shows the estimated groundwater level and salinity contours, and inferred groundwater flow vectors. Figure 5 shows typical hydrogeological cross section AA’ (refer Figure 4 for location).

3.3.1 Groundwater Occurrence

Golder (2000a) identified three types of aquifers likely to occur in the region *viz.* alluvial, fractured rock and chemical aquifers (Figure 6). Alluvial aquifers are saturated alluvial sands and gravels, generally occupying recent and palaeo-drainage systems. There are no known major saturated palaeochannel aquifers within 10 km of the site. An unsaturated palaeochannel located above the water table has been mapped through the mine lease (Figures 4 & 5).

Fractured rock aquifers are associated with major fault zones or splay faults and are of limited significance in the regional groundwater system. Localised fractured rock faults are located at the mine lease, and are generally associated with the laterite ridges in the west of the lease. The site specific investigations conducted by Golder (2000a, 2000g) identified a fractured rock aquifer in the north-west of the site. The permeability of these fractured basement rocks and the weathered derivatives above them appear to be low, in the range of 1×10^{-9} to 1×10^{-7} m/s.

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[3] Using Boughton's SFB daily increment catchment yield model, uncalibrated; (Golder, 2000e).

Chemical aquifers occur where chemical alteration of rock mass has caused enhanced permeability or storage. The main occurrence of such an aquifer at the Project site is the siliceous cap-rock of the dunite intrusion that occurs beneath the mining lease.

No aquifers were identified within the potential zone of influence of the TSF and evaporation ponds. The topographic ridge separating the main mining area and the proposed location for the TSF and evaporation area is inferred to be coincident with a local groundwater divide (Golder 2000g).

Groundwater would also flow through the 'tight' fractures and joints in the basement rock. No perched aquifers were interpreted to exist at the site. This implies that once saturation of the soil and rock is encountered, it is interpreted to be continuous with depth below the water table.

3.3.2 Areas of Recharge and Discharge

Recharge to the groundwater system is generally confined to catchment divides, where basement rock may outcrop and present open fractures and joints to the atmosphere. Local groundwater associated with this recharge is generally fresh to brackish. A groundwater recharge zone was identified on the laterite ridge located in the north-west of the mining lease.

A monitoring bore in this area (GAM1) (Figure 7) intersected gabbro to 44 m depth, and produced an airlift yield during drilling of 110 kL/day with a salinity of 177 mg/L (fresh). These results indicate enhanced permeability and recharge in the zone surrounding this test bore.

In the region of the mine lease, no major surface water expressions (ie. wetlands, local lakes or rivers) into which groundwater discharge is expected to occur were found. Some waterlogged areas that exist on site are however likely to become zones of groundwater discharge during the summer months. Occasional gravel pits and other small depressions in the topography may intersect the water table.

3.3.3 Flow Directions and Velocities

Groundwater flows from areas of recharge to areas of discharge. Figure 4 shows the plan view of expected directions of groundwater flow, and Figure 6 shows a schematic cross-sectional representation of the expected groundwater flow regime in this region. The figures show the flow of groundwater from zones high in the topography where recharge is occurring, towards discharge zones low in the catchment.

This behaviour typically results in groundwater contours mimicking the topography, although at a reduced amplitude. The groundwater flow directions would generally be normal to the groundwater contours. The average groundwater velocity surrounding the mine lease was calculated as 3×10^{-4} m/day, equivalent to 0.1 m/year (Golder, 2000a).

4 FIELD INVESTIGATIONS

4.1 REGIONAL BORE SURVEY

A regional bore survey was conducted between 10 August 1999 and 12 September 1999. The survey involved:

- Reviewing regional bore information provided by the Department of Land and Water Conservation (DLWC).
- Conducting a survey on water quality, bore yields and water depths for bores indicated to be located on properties.
- Measuring bores for depths to the water table.

Table 3 summarises the results of the bore survey, as detailed in Golder (2000a). Figure 8 provides the locations of boreholes surveyed.

Table 3
Summary of Bore Survey Results

Name	Easting (m AMG[1])	Northing (m AMG[1])	Depth m	Standing Water Level m	Yield L/s	Salinity mg/L	Aquifer	Intended Purpose
2976	5548663	66383669	121.9	42.7	1.1	Salt	-	-
10517	5549887	66377878	42.7	19.7	3.7	Brackish	-	General Use
10519	5548594	66379707	61	-	-	Vsalt	-	-
10520	5546106	66381213	68.6	-	-	Vsalt	-	-
16768	5534365	66378554	24.7	17.1	0.3	1001-3000	-	General Use
21446	5537604	66380790	39.6	18.3	0.3	3001-7000	Fractured rock	Domestic Stock
21516	5548536	66371853	19.8	-	-	Suitable for stock	-	Stock
28264	5543167	66378812	64	-	0.6	Brackish	Fractured rock	Irrigation
32873	5549023	66380787	26.2	-	-	-	-	Stock
50197	5532597	66377585	39.6	18.3	0.2	-	-	-
57335	5534251	66375284	48	27	0.4	Poor	-	Domestic Stock
57335b	5533348	66375144	30	25.9	Trace	-	-	Domestic Stock
58028	5548700	66371120	36	18	0.8	-	Fractured rock	Domestic Stock
58029	5547895	66368970	50	-	0.1	-	Fractured rock	Domestic Stock
58030	5549460	66367940	23	12	0.9	-	Fractured rock	-
64728	5533500	66377725	70.5	32.8	0.8	-	Fractured rock	Domestic Stock
10692	5548253	66365814	46.6	29.3	0.1	1001-3000	Fractured rock	Domestic Stock
54026	5548036	66366474	75	-	-	-	-	Domestic Stock

[1] Australian Mapping Grid

4.2 HYDROGEOLOGICAL INVESTIGATIONS

The site hydrogeology investigations included:

- Hydrogeological drilling programme and the installation of monitoring piezometers.
- In-situ permeability testing.
- Water quality sampling and analysis.

Seventeen boreholes were drilled during the hydrogeological investigation, 15 on site and 2 to the north of the site. Figure 7 shows the borehole locations. Constructed details of the monitoring bores are presented in Golder (2000a) and summarised in Table 4.

The bores were completed by installing 6 m to 9 m of slotted PVC casing, then solid PVC pipe to the surface. The annulus outside the screened/slotted horizons of all holes was filled with coarse graded sand, sealed with bentonite and then backfilled to surface using drilling spoil.

Groundwater levels were measured on 12 September 1999, after completion of the drilling and well development programme. Groundwater levels were highest in the north-west of the site, from where groundwater is interpreted to flow south-east towards the palaeochannel, then north-east in the direction of the fall of topography. Groundwater also flows towards the palaeochannel from the south of the site. In the most south-eastern extent of the site, the flow direction is inferred to be to the south-east and then to the north-east again, presumably towards another palaeochannel that passes north-east past Anderson’s Pit.

The hydraulic testing data was analysed to provide estimates of hydraulic conductivity (or permeability). Results were used in the groundwater modelling and are summarised in Section 10. The calculated hydraulic conductivities are low, consistent with generally low to non-existent flows from the bores in the region, and the monitoring bores installed during the drilling programme.

Table 4
Summary of Monitoring Bore Details

Borehole	East (m AMG[1])	North (m AMG[1])	Ref Pt. RL. (m AHD[2])	Depth (m)	Water Intersections (m)	Field pH	Electrical Conductivity (μS/cm)	Temperature (°C)	Screened Intervals (m)[3]	Static Water Level (m)	Static Water Level (m AHD[2])
GAM-1	536270	6376164	301.2	44	42.5	7.87	283	20.6	37.9 - 43.9	28.165	273.1
GAM-2	536735	6375199	300.3	52.7	43	9.84	847	20.7	46.3 - 52.3	30.29	270.0
GAM-3	537843	6375277	293.3	48.2	35.5	-	-	-	41.9 - 47.9	45.81	247.5
GAM-4	537890	6373630	292.7	48.2	44.5	8.48	2059	21.2	42 - 48	27.48	265.3
GAM-6	539021	6373754	294.6	57.4	-	8.55	4950	20.3	51.2 - 57.2	45.21	249.3
GAM-7	539097	6374832	289.2	57.7	35.5	9.61	718	20.7	51.1 - 57.1	47.48	241.7
GAM-8	539582	6372794	293.7	57.4	-	8.44	9250	18.9	51 - 57	48.21	245.5
GAM-9	539895	6376025	279.6	52.9	33	8.48	1102	20.9	46.3 - 52.3	42.15	237.5
GAM-10	540450	6373412	283.1	52.9	46.5	8.44	5160	20.4	46.5 - 52.5	33.48	249.7
GAM-11	541000	6372603	281.8	61.9	-	9.63	11700	21.9	55.5 - 61.5	41.03	240.8
GAM-12	541263	6374259	280.4	57.4	-	-	-	-	51 - 57	30.11	250.3
GAM-13	541682	6377276	270.5	49.3	39.5	8.31	3740	22.5	38 - 47	25.45	245.1
GAM-14	541674	6375037	282.8	99.5	-	-	-	-	90 - 96	42	240.8
GAM-14b	541668	6375037	282.9	71.8	-	-	-	-	64 - 70	63.995	218.9
GAM-14c	541663	6375038	283.1	39.3	-	-	-	-	33 - 39	36.065	247.0
GAM-15	541438	6371773	294.2	70.7	-	8.69	3770	18.9	64.5 - 70.5	55.59	238.6
GAM-16	540858	6378336	272.8	69.7	10	-	-	-	56.7 - 65.7	51.98	220.8

[1] Australian Mapping Grid

[2] Australian Height Datum

[3] Metres Below Ground Level

Borehole locations shown on Figure 7

4.3 GEOLOGY

The geology intersected by the hydrogeological drilling programme is considered representative of the site and the local region, and is summarised in Table 5.

Table 5
Summary of Geological Results

Lithology	Location	Potential Aquifer
Laterite	Laterite was encountered in the north-west of the site in boreholes GAM2, GAM3, GAM6, GAM7 and GAM16. The laterite was always underlain by the siliceous cap-rock. Depths range 15 to 45 m below ground level	Where fractured, good aquifer potential identified in NW of site
Ultrabasic intrusives	Dunite was not encountered in any of the boreholes.	Caprock to this unit has enhanced permeability and may provide water supplies
Ultrabasic intrusives	Pyroxenite / gabbro / diorite – these ultrabasic rocks were encountered in all of the boreholes at depths ranging from 3 to 43 m. They tended to underlie colluvium and residual material.	Only in heavily fractured zones, none discovered in this programme of drilling
Metasediments		As above
Residual soil/ alluvials	Covers the low-lying areas of the site, to depths of up to 2 m.	No
Palaeochannel	A palaeochannel up to 1,500 m wide and 35 m deep passes through the site in a north easterly direction. The alluvium comprises silts, clays, gravels, quartz and rock fragments. The palaeochannel was encountered in boreholes GAM7, GAM9, GAM13 and GAM16.	Where saturated, the sand and gravel fraction of the palaeochannel would be a significant aquifer

Geotechnical sections and graphical borehole logs are presented in Golder (2000a).

4.4 WATER QUALITY

Water samples were collected from boreholes GAM1, 2, 4, 6, 7, 8, 9, 10, 11, 13 and 15 and Anderson’s Pit (Figure 7). The samples were tested on site for pH, conductivity and temperature. The results of field and laboratory test work are presented in Golder (2000a) and summarised in Table 6.

Table 6
Summary of Water Quality Results

Borehole	Sample Date	pH	EC µS/cm	TDS	Alkalinity ($CaCO_3$)	Ca	Mg	Na	K	Cl	SO_4	HCO_3	CO_3	Fe	As	Cd	Cr	Cu	Mn	Ni	Pb	Zn	Hg	Nitrate	Nitrite	PO_4
GAM-1	10/09/99	7.3	307	214	61	9	nd	53	nd	30	37	61	nd	nd	-	-	-	-	0.004	-	-	-	-	0.05	nd	0.05
GAM-2	11/09/99	7.73	798	528	399	49	59	50	2	34	21	399	nd	nd	-	-	-	-	nd	-	-	-	-	0.32	nd	0.11
GAM-4	11/09/99	7.54	2,170	1,670	441	97	135	146	6	450	54	441	nd	nd	-	-	-	-	0.028	-	-	-	-	3.10	0.12	0.13
GAM-6	11/09/99	7.5	5,060	4,210	570	111	306	465	22	1,230	277	570	nd	nd	nd	nd	0.002	0.004	0.151	0.027	nd	0.007	nd	0.01	nd	0.11
GAM-7	3/09/99	8.6	1,320	740	348	4	66	172	9	206	39	337	11	nd	-	-	-	-	0.017	-	-	-	-	0.22	0.15	nd
GAM-8	11/09/99	8.14	11,100	7,970	849	81	282	2050	81	2,130	2,060	849	nd	nd	-	-	-	-	0.556	-	-	-	-	0.26	nd	0.06
GAM-9	10/09/99	8.48	1,270	802	610	3	136	81	4	75	33	602	8	nd	nd	nd	0.059	0.001	nd	0.002	nd	0.006	nd	nd	nd	0.07
GAM-10	12/09/99	7.76	5,780	3,660	765	111	287	705	27	1,260	463	765	nd	nd	-	-	-	-	0.070	-	-	-	-	0.05	nd	0.08
GAM-11	12/09/99	7.53	13,800	10,100	533	289	464	2040	69	3,760	1,160	533	nd	nd	nd	nd	0.002	0.007	nd	0.012	nd	0.006	nd	0.40	0.04	0.06
GAM-13	11/09/99	7.95	4,410	3,100	789	71	287	431	16	879	251	789	nd	nd	nd	nd	0.002	0.002	0.034	0.003	nd	0.006	nd	12.30	nd	0.06
GAM-15	12/09/99	7.96	3,560	2,600	780	67	154	571	23	400	724	780	nd	nd	-	-	-	-	0.059	-	-	-	-	0.32	0.04	0.05
Anderson’s Pit	11/09/99	8.18	132	70	64	4	8	7	8	4	nd	64	nd	nd	-	-	-	-	nd	-	-	-	-	0.21	nd	nd
Livestock Guidelines[1]				3000		1000	600				1000				0.5	0.01	1.0	0.5		1.0	0.1	20	0.002	30	10	
Raw Drinking Water Guidelines[1]		6.5-8.5		1000				300		400	400			0.3	0.05	0.005	0.05	1	0.1	0.1	0.05	5	0.001	10	1	
Limit of Detection		0.01	1	1	1	1	1	1	1	1	1	1	1	1	0.10	0.01	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.0001	0.01	0.01

NB: All results are in mg/L unless otherwise stated.

[1] ANZECC, 1992

nd: Not detected

-   Not tested

A Piper diagram for water samples obtained during field investigations is presented in Figure 9. Figure 9 indicates:

- There is a wide spread of water composition across the site, but a broad correlation of water types can be recognised from bores located in a similar position in the groundwater catchment.
- The majority of waters are sodium chloride dominant.
- A group of bores with similar water characteristics are bores GAM1, 4, 7 and 9. These bores are on the west of the site and generally in the vicinity of the palaeochannel. Water samples from these bores exhibited moderate to high Ca and Mg, low to moderate Na and K, low SO_4, low to moderate Cl and moderate to high HCO_3.
- Similar water characteristics were also present in bores in the vicinity of the TSFs and evaporation ponds. These bores exhibited low values of Ca and Mg, moderate to high Na and K, low to moderate HCO_3 and SO_4, and moderate to high Cl.
- Groundwater bores GAM6 and GAM13 (eastern side of palaeochannel) displayed similar characteristics. Location and groundwater composition for these bores is intermediate of those described above.

Overall, groundwater quality surrounding the Project area is generally poor but highly variable, and expected to range from saline (>10,000 mg/L) when sourced from zones of low permeability and slow groundwater movement and/or discharge areas to fresh (<1,000 mg/L) adjacent to areas of recharge.

Results from the groundwater monitoring bores indicate that water quality is variable, but follows a pattern that can be interpreted in terms of recharge, groundwater flow directions and residence time. The results indicate that the groundwater is only suitable for stock watering at selected locations, with the exception of water sourced from ‘Berrilee’, where it is of an acceptable standard for domestic purposes.

5 GEOTECHNICAL INVESTIGATIONS

Geotechnical investigations were undertaken for the mine pits, limestone quarry, Tailings Storage Facility and evaporation ponds and reported in Golder (2000b & 2000d). Presented below is a summary of the findings of these studies.

5.1 MINE PITS

A detailed description of field investigations and laboratory test work undertaken on samples taken from the mine pit areas is presented in Golder (2000d). A summary of the laboratory test results is provided in Table 7.

Table 7
Summary of Laboratory Testing Results

Sample Number	Description	Confining Pressures kPa	Cohesion kPa	Angle of Friction
SY14	Lateritic Conglomerate	100, 150, 200	175	40^{o}
SY10	Siltstone (Goethitic Zone)	250, 500, 750	285	36^{o}
SY5	Dunite (Saprolite)	800, 1000, 1200	55	27^{o}

Borehole information indicates the deposit could be broadly subdivided into the six main geotechnical stratigraphic units listed in Table 8. The thickness and depth below surface to these units is variable across the deposit. Similarly the geotechnical characteristics (strength, weathering, discontinuities, etc) of each unit are also expected to be variable across the deposit. Geotechnical characteristics presented in Table 8 are based on visual estimation and the testwork undertaken.

Table 8
Mine Pits - Anticipated Ground Conditions

Stratigraphic Unit	Thickness[1] m	Depth to Base [1] m	Geotechnical Characteristics
Residual Soil	3 (0 – 5)	3 (0 – 5)	• stiff to hard red brown sandy clay / gravelly clay.
Lateritic Conglomerate	7 (2 - 25)	10 (2 - 25)	• extremely low to low strength, extremely weathered lateritic conglomerate • minimal discontinuities present.
Siltstone (Goethitic Zone)	20 (5 - 25)	30 (15 - 35)	• extremely low to low strength, extremely weathered goethitic siltstone • occasional thin very high strength silicified zones present • rare to occasional discontinuities present • discontinuities are wavy, slickensided, clean or clay infilled, dipping at 10 – 80^{o} (30 – 60^{o} dips common).
Silcrete/Silicified Siltstone	5 (1 - 7)	35 (25 - 40)	• very high strength, distinctly weathered silcrete / silicified goethitic siltstone • minimal discontinuities present.
Dunite (Saprolite)	3 (1 - 5)	38 (26 - 45)	• extremely low to low strength, extremely weathered dunite thin serpentine veins present • wavy, slickensided, clay infilled discontinuities dipping at 30 – 70^{o} present.
Dunite (Saprock)	-	-	• medium to high strength, distinctly weathered dunite • occasional discontinuities present.

[1] ‘Thickness’ and ‘Depth to Base’ values are provided as a mean with measured range shown in parenthesis.

The overall slope stability of the mine pit walls was assessed by conducting two dimensional limit equilibrium stability analyses using programme SLOPE/W. The analyses assumed the pit is 30 m deep with a smooth overall slope (ie. individual batters and berms were not modelled) inclined at 75° and 60° from horizontal. Both circular (rotational) and active – passive wedge failure modes were analysed.

Results presented in Golder (2000d) indicate an overall slope angle of 60° from horizontal for 10 m high batters and 3 m berms, or 14 m high batters and 5 m wide berms would be suitable. Batters excavated in residual soil should be inclined at 45° from horizontal and vegetated for long term stability.

5.2 LIMESTONE QUARRY

It is proposed to develop the Gillenbine quarry to provide limestone for the Syerston Project process plant. The quarry is located about 20 km from the site between Fifield and Trundle (Figure 1). The limestone would principally be used for metallurgical requirements in the plant, however its suitability as a construction aggregate has been assessed.

Table 9 presents the anticipated ground conditions based on a review of the point load test results, borehole logs and core photographs. The general stratigraphy appears to be a thin residual soil cover overlying a Calc Tufa bed followed by interbedded Calcilutite and Calcarenite resting on a black carbonaceous shale basement.

Table 9
Limestone Quarry - Anticipated Ground Conditions

Depth Below Surface (m)	Stratigraphic Unit	Geotechnical Characteristics
0 – 0.4	Residual Soil	• Dark brown clay (stiff to hard).
0.1 – 3.0	Calc Tufa	• Extremely weathered, very low to low strength with minimal discontinuities.
1.0 - > 25.0	Interbedded Calcilutite & Calcarenite	• Extremely to distinctly weathered, slightly fractured to fractured, interbedded low to high strength Calcilutite and low to very high strength Calcarenite. • Occasional calcareous clay infilled cavities 0.1 to 1.0 m high present. • Discontinuities consist of bedding partings and 1 - 2 joint sets. Bedding partings are planar, smooth, iron stained with 10-20°dip. Joints are planar to wavy, rough, iron stained with 60-80°dip.
14.0 - > 25.0	Black Shale	• No available information.

Groundwater was encountered in some of the RC boreholes between 16 and 21 m below the surface. An inflow rate of 0.5-1.0 L/s was estimated for one of the boreholes. On the basis of point load testing, it is considered likely that the higher strength zones of limestone would be suitable for crushing to produce road pavement aggregates and for use as erosion protection of waterway channels.

5.3 TAILINGS STORAGE FACILITY AND EVAPORATION PONDS

This section provides a summary of geotechnical investigations undertaken for the TSF, evaporation ponds and the evaporation surge dam, as reported in Golder (2000b).

The process plant tailings would be stored in a tailings storage facility (TSF) consisting of two cells (north and south), that would be constructed in the south-east corner of the mine lease (Figures 2 & 3). Supernatant and rainfall runoff water would be recovered from the surface of the TSF and decanted into the evaporation ponds and evaporation surge dam for evaporative disposal.

The TSF would cover a total area of approximately 217 ha. The topography under the southern cell slopes steeply from 310 m RL at the south-west end to approximately 285 m RL in the north-east corner. The topography under the northern TSF is relatively flatter with a general fall from the north to the south-east of about 8 m, while a flat broad valley incises the area from the south-east.

The evaporation ponds, which lie to the east of the TSF would cover a total area of about 121 ha. They would be divided into 7 ponds of varying elevation and constructed down the natural topography. The topography under the evaporation ponds slopes relatively gently from about 287 m RL at the south-west end to about 277 m RL (Golder, 2000f).

The evaporation surge dam, immediately to the north of the TSF, would cover an area of approximately 56 ha (Figure 2). The dam storage would fill a broad east-west trending valley that slopes down to the east from 285 m RL to 277 m RL.

The geotechnical investigations provided information for the design of the TSF and process water evaporation system structures, including:

- soil profile;
- depth to rock;
- permeability of the underlying soil strata; and
- suitability of the soils for construction purposes.

The investigation comprised of 17 test pits excavated to depths between 0.9 m and 3.4 m, and 8 cored boreholes to depths of between 12.3 and 36.9 m (Figure 3). A soils survey of the old mine spoil piles was also carried out, including the development of 11 test pits and a laboratory test work programme. Logs for the test pits and boreholes are presented in Golder (2000b).

5.3.1 Geotechnical Investigation Findings

In the area of the proposed TSF and evaporation ponds, soil cover over the underlying bedrock was generally 0.5 to 3 m thick. The exception to this was found at investigation locations GADC5, GASC5 and GASC6 (Figure 3) where the thickness of soil cover was in the range of 5.2 to 8.9 m thick. The thicker areas of soil appeared to correlate with areas of lower topography. The soil layer comprised very stiff to hard silty, sandy or gravelly clays. Below the soil cover, extremely low to low strength rock was encountered. No groundwater was encountered to the depth of the test pit investigation or open hole drilling.

Field investigations reported in Golder (2000b) found that the upper 2 to 3 m of the mine spoil piles comprised medium dense to dense sandy silts or silty sands with some gravel. In two of the test pits cobbles and boulders in a matrix of sandy silts/silty sands were encountered below approximately 1 m. The materials were in a relatively dry condition and groundwater was not encountered.

Laboratory testing was conducted on selected samples from the test pits in the TSF, evaporation area and the old mine spoil piles, to confirm their suitability for use in the construction of the TSF and evaporation pond embankments. The results of this test work programme are presented in Golder (2000b).

The geotechnical investigation indicated that the surface conditions at the proposed TSF, evaporation ponds and evaporation surge dam sites are suitable for the construction of the proposed facilities from a geotechnical perspective. Hydrogeological considerations are addressed in Section 10.

The subsurface materials and the proposed fill materials are considered to be of sufficient strength to support the proposed embankments and future stored tailing without stability concerns (Golder, 2000b). Detailed stability analyses for the TSF is presented in Section 6.

Geotechnical investigations found that:

- The mine spoil material would be suitable for the construction of the TSF starter embankments, and the evaporation ponds and evaporation surge dam embankments.
- The surficial soils within the TSF area would also be suitable for the construction of the TSF starter embankments, and the evaporation ponds and evaporation surge dam embankments.

The silt and clay content of the soils tested is variable. The soils that contain higher clay contents would be more suitable for use as the core of the evaporation pond and surge dam embankments. The results of the laboratory permeability testing on compacted surficial soils from the TSF and mine overburden showed a range in permeability of 7.5×10^{-8} to 2.6×10^{-11} m/s. At the time of construction it would be possible to delineate areas of material that would be suitable for either the general fill or core material for the evaporation pond and surge dam embankments.

6 TAILINGS STORAGE FACILITY

This section presents a summary of the preliminary design of the TSF, evaporation ponds and evaporation surge dam, based on details presented in Golder (2000f). The scope of this study included:

- Determination of the area required to store the annual tailings output from the proposed process plant for a 20 year period.
- Determination of tailings geotechnical parameters for stability analyses of the proposed TSF.
- Stability analyses of the proposed TSF.
- Modelling of seepage potential from the proposed TSF.
- Preliminary design of the proposed TSF.

6.1 TAILINGS DESCRIPTION

The tailings are the result of the re-precipitation of the lateritic nickel ore, following a high temperature pressure acid leach (PAL) process. During this process the form of some of the original oxides changes, resulting in an increase in the specific gravity (SG).

Approximately 2% of concentrate would be recovered from the 2 Mtpa of ore in the PAL process. The tailings would then be neutralised by the addition of limestone, to raise the pH from below 2 to above 6.5. Approximately 2.55 Mtpa of neutralised tailings would result from this process.

Tailings produced from the process plant would have the following indicative characteristics:

- Solids concentration of 48%.
- Total dissolved solids (TDS) concentration of approximately 26,600 mg/L.
- Temperature of approximately 80°C.

Table 10 provides a summary of the predicted typical Syerston Project tailings slurry constituents.

Table 10
Typical Tailings Constituents

Constituent	Solution mg/L
Aluminium (Al)	42
Chlorine (Cl)	524
Cobalt (Co)	4
Chromium (Cr)	6
Iron (Fe)	2
Potassium (K)	<1
Magnesium (Mg)	8,692
Manganese (Mn)	4
Sodium (Na)	450
Nickel (Ni)	75
Silicon (Si)	10

Source: Black Range Minerals (2000)

Tailings would be pumped to the TSF as a slurry. The solution portion would contain magnesium sulphate ($MgSO_4$) at concentrations of approximately 25,000 mg/L (BRM, pers. comm.).

6.1.1 Tailings Geotechnical Characteristics

Details of the suite of laboratory tests undertaken on pilot plant tailings samples are presented in Golder (2000f). Table 11 presents a summary of the predicted tailings geotechnical characteristics based on the test results.

Table 11
Summary of Tailings Geotechnical Characteristics

Characteristic	Value
Solids Concentration	43%*
Specific Gravity (SG)	3.63 (average)
Sizing	6% < 2 µm
	95% < 75 µm
Plasticity Index	10 (average)
Linear Shrinkage Limit	26% (average)
Shear Box Shear Strength (Ultimate):	
• Cohesion (kPa)	23.4
• Friction Angle (ϕ)	20.8°
Shear Box Shear Strength (Failure):	
• Cohesion (kPa)	22.5
• Friction Angle (ϕ)	14.4°
Undrained Dry Density	0.97 t/m³ (average)
Drained Dry Density	1.17 t/m³ (average)

* Predicted to vary from 42% to 48%

Climatic drying tests were also conducted under laboratory conditions to replicate the summer and winter climate of the Syerston Project area. The results of these tests are presented in Golder (2000f) and indicate that over time climatic effects can be expected to result in an increase in the density of the tailings. Results under the climatic conditions tested indicated that the tailings average dry density may reach approximately 1.25 t/m³.

A standard consolidation test was also undertaken on the tailings sample. The test method and results are reported in Golder (2000f). The consolidated test results indicated that if the tailings are desiccated to a dry density of 1.25 t/m³:

- At a depth of 30 m, equivalent to a load of 580 kPa, the tailings dry density should rise to approximately 1.56 t/m³ from 1.25 t/m³ at the surface.
- Based on estimated and measured values, the permeability of the tailings should decrease from a value about 2.1×10^{-8} m/sec at the surface to about 5×10^{-9} m/sec under a load of 30 m of tailings.
- Based on calculated values, the permeability of the tailings should decrease from a value of approximately 1×10^{-10} m/sec at the surface to approximately 3×10^{-11} m/sec under a load of 30 m of tailings.

For the purposes of analysis, a tailings vertical permeability of 3×10^{-7} m/sec has been extrapolated from the measured permeability values to reflect the initial settled dry density.

6.2 TAILINGS STORAGE FACILITY DESIGN

The TSF would be designed to store the tailings generated from the process plant at 2.55 Mtpa over an operational period of over 20 years, at an initial dry density of 1.1 t/m^3. The TSF is to be located 300 m to the east of the proposed process plant (Figure 3).

6.2.1 Tailings Storage Facility Layout

The TSF would be divided into two cells to allow tailings deposition to cycle between them. Tailings deposition would be cycled so that only one cell would be active at any time. It is proposed to develop the southern cell first, followed by the northern cell 3 years later.

The northern and southern cells would have areas of 113 ha and 104 ha respectively. Key features of the proposed TSF layout include (Figure 3):

- Near square layout to assist in centrally locating the decant ponds.
- Earth fill starter perimeter embankment with subsequent upstream lifts constructed from desiccated tailings.
- Central gravity decant inlet to deliver decanted waters to the evaporation ponds. Intermediate inlets would facilitate decantation of liquors during the initial development stages of the cells.
- Decant flows that exceed the capacity of the evaporation ponds would be redirected to the evaporation surge dam.
- Perimeter filter drain at the inner toe of the starter embankment, to control the internal phreatic surface and to intercept potential seepage waters.

Following 20 years of tailings deposition the predicted embankment heights of the north and south TSF cells would be up to approximately 30 m.

6.2.2 Starter Embankment

The TSF starter embankment would be constructed around the perimeter of the TSF (Figure 3). The starter embankment would be sized to provide up to 5 years tailings storage (depending on operational requirements) and would have a minimum height of 1.5 m.

The starter embankment would not be built as a water retaining structure, as adequate under-drainage at the inner toe of the embankment would be provided to prevent the development of ponding within the TSF (Figure 10). The underdrain would also have a trench drain to intercept shallow seepage.

6.2.3 Upstream Embankment Lifting

The TSF perimeter embankments would be raised using the upstream construction method.

The TSF embankment lifts would be constructed on top of the deposited tailings in an upstream direction (Figure 11). Downstream lifts would be required if the strength of the tailings were insufficient to support the embankment lift. The upstream method minimises the area of disturbance and earthworks volume required for the TSF.

To enhance the potential for upstream lifting, the TSF would be operated to limit the rate of rise of the stored tailings to less than 1.5 m/year. Desiccated tailings would be used for the construction of the raised perimeter embankments, which would be rehabilitated progressively with a soil and vegetative cover (Figure 12).

6.2.4 Seepage Control

Modelling of potential seepage migration from the proposed TSF and the evaporation ponds is reported in Golder (2000a) and summarised in Section 10 of this Appendix. Seepage control measures include a low permeability clay liner constructed under the TSF by compacting the in-situ clay material to a depth of 1 m. Laboratory testing has indicated that the clays would achieve a permeability of at least 1×10^{-9} m/sec.

A seepage interception drain would be installed at the inner toe of the starter embankment to intercept seepage through the tailings and surficial soils under the TSF. This drain would also control the level of the phreatic surface within the tailings and would comprise a drainage blanket overlying a drainage trench. Seepage collected in the seepage interception drain would be drained under the TSF starter embankment to seepage collection sumps. These sumps would be dewatered to either the TSF cells or the evaporation ponds.

Seepage water quality is likely to be similar to the incoming tailings slurry, at a TDS of approximately 26,600 ppm. The dominant dissolved salt would be magnesium sulphate ($MgSO_4$) (Golder, 2000f).

6.2.5 TSF Stability Analysis

The stability of the TSF cells has been assessed using the widely used finite element programme SLOPE/W. Shear strengths were obtained in laboratory testing for the tailings and the foundation soils. The results of stability analysis presented in Golder (2000f) indicate that the TSF would have adequate stability under both static and seismic loading conditions both during the life of the mine and once operations cease.

6.2.6 Decant System

A gravity decant system would be used to remove excess water from the decant pond to the evaporation ponds. The decant flows would be controlled by a weir flowing into a decant tower. The location of the decant towers and pipelines are shown in Figure 3.

The TSF decant system would be sized to remove the runoff generated from the 1 in 100 year ARI[4] storm event of 72 hours duration from the TSF surface within 5 days.

An earthworks ramp would be used to access the decant tower inlets (Figure 3). These ramps would be wide enough to carry trucks and earthmoving equipment. At the end of the ramps there would be a walkway connecting the ramp to the decant inlet, to allow operator access.

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[4] Average Recurrence Interval

6.3 TAILINGS DEPOSITION

The tailings would be pumped to the TSF from the process plant in 250 mm diameter pipes. At the TSF the pipeline would be continued around the four sides of each TSF cell to form a ringmain (Figure 3). The tailings slurry ringmain is to be laid on the inside crest of the starter embankment. The tailings slurry would then be deposited into the TSF through 100 mm diameter spigots let into the ringmain at 50 m centres.

The perimeter embankment around the tailings beach, which is to be raised in an upstream direction, would have a crest width of about 7 m and an embankment lift height of 1.5 m. The slope of the outer face of the embankment would be constructed with a 3(H) in 1(V) slope and an inner slope of 1.5(H) in 1(V).

When the tailings beach has filled to within 300 mm of the inner crest level of the perimeter embankment, tailings deposition would move to the next cell. At this time the ringmain is to be removed from the filled cell to allow embankment lift construction.

Typically lateritic nickel tailings beaches at a slope of less than 0.5%, when pumped in a slurry with a solids concentration of less than 40%. However, it is expected that the Syerston tailings would beach at an angle of about 1%, as it would be pumped into a slurry with a solids concentration of 48%.

6.4 CATCHMENT PADDOCKS

Prior to the successful completion of embankment rehabilitation, catchment paddocks would be used to contain potentially sediment laden runoff from the external batters of the TSF embankment. Collected runoff would be pumped to the TSF or evaporation ponds.

A series of runoff catchment paddocks would be developed around the toe of the TSF to contain runoff from the external embankment batters. These paddocks would be approximately 20 m wide, with outer embankments about 1.5 m high. Cross walls would be built to provide temporary water holding ponds. The catchment paddocks would be designed to contain the runoff generated from the 1 in 100 year ARI rainfall event or 72 hours duration from 50% of the external embankment of the TSF.

6.5 REHABILITATION

The outer face of each embankment raise would be rehabilitated immediately the raise has been completed. Typically at least 500 mm of spoil would be placed over the tailings and then this would be covered with 200 mm of topsoil. The topsoil would then be seeded to encourage a rapid vegetative cover. The berms created during the step-in would be rehabilitated once they are no longer required as access ways, following the same procedure as used for the outer slopes.

7 PROCESS WATER EVAPORATION SYSTEM

Decanted waters removed from the TSF would be discharged into the evaporation pond system for evaporative disposal. These waters would have an estimated initial TDS of approximately 26,600 ppm or greater, depending on the climatic conditions pertaining at the time. Minimal reuse of these waters in the process plant can occur, due to process make-up water quality constraints. Further investigations are underway on the possibility to reuse decant water within the process. It is proposed to use an average of 0.48 ML/day for dust control on the mine haul roads within controlled catchments.

Seven evaporation ponds, with a combined area of 121 ha, would be located to the east of the TSF (Figure 3). In addition to these ponds, a 56 ha evaporation surge dam would be located immediately north of the TSF (Figure 2).

7.1 EVAPORATION POND DESIGN

To provide a sufficient water surface area, the seven evaporation ponds have been designed as a series of contour ponds, with a 1.5 m fall between each cell. The base of each pond would be approximately level, so that:

- the maximum liquor surface area is available at all times; and
- the compacted in-situ clay liner remains saturated.

The water balance study (Section 8) was conducted with a maximum pond embankment height of 3 m, providing 0.5 m freeboard for storm surge capacity. The total storage capacity of the ponds would be approximately 2,420 ML. Spillways would be designed for the probable maximum flood (PMF) event and would be located in the eastern embankment of each evaporation pond cell.

The surge dam would require an 8 m high embankment (Figure 2). The surge dam would provide approximately 1,500 ML of storage capacity with a 1 m operating freeboard. Four evaporation ponds would be constructed within the surge dam, to provide maximum evaporative area.

The surge dam embankment has been designed as a water retaining structure, with a compacted earth zoned structure and a clay cutoff trench connected to a clay core. There would be a drain behind the clay core to intercept seepage.

The surge dam embankment would have upstream and downstream batter slopes of 3(H) in 1(V). The downstream batter would be revegetated immediately following construction. The upstream batter would be covered with a 300 mm layer of riprap.

Stability analyses of the surge dam embankment under static and dynamic conditions, using the shear strength values developed for the TSF embankment, indicates that the embankment has an acceptable Factor of Safety under all loading conditions (Golder, 2000f).

7.2 EVAPORATION POND SYSTEM OPERATION

To maximise the evaporative effect of the evaporation ponds and ensure the clay liner is submerged, an even depth of water would be maintained across all of the ponds.

The decant water from the TSF cells would gravitate through the decant pipelines to the sump in evaporation pond 4 (Figure 13). The waters would then be distributed into the other 6 evaporation ponds. When the decant flow exceeds the capacity of the evaporation ponds during periods of high or consistent rainfall, flows would be redirected to the evaporation surge dam.

The operational aim of the evaporation surge dam is to keep the water level as low as possible, to ensure that its surge capacity is available to contain runoff from large rainfall events.

Whenever there is spare capacity in the evaporation ponds, water would be pumped from the surge dam and distributed through the evaporation ponds. At all times the floor of the evaporation ponds within the surge dam would be kept covered with water to protect the clay liner. A spillway would be installed in the northern end of the surge dam embankment, with a design capacity sufficient to pass the PMF flow.

Waters stored in the evaporation ponds and surge dam would contain high TDS levels, predominantly magnesium sulphate. These salts would crystallise out when saturation concentrations are reached due to evaporative concentration. In order to maintain the required operating capacity of the evaporation ponds and surge dam, these salts would be periodically removed and deposited in the TSF cells. Section 8 discusses the TSF and evaporation system water quality and quantity balance.

The evaporation ponds and the surge dam would be operated to maintain a freeboard sufficient for the storage of the volume or runoff generated from a 1 in 100 year ARI rainfall event of 72 hours duration.

8 PROCESS WATER MANAGEMENT

A water quality and quantity balance for the proposed TSF and evaporation pond system is presented in Golder (2000e). Presented in this section is a summary of the findings of Golder (2000e). The objective of this study was to size and design the evaporation ponds and surge dam for the containment and evaporative disposal of supernatant waters dewatered from the TSF.

As described in Section 6.2 the TSF would be divided into the north and south cells, with surface areas of approximately 113 and 104 ha respectively. It is intended that tailings disposal would be carried out in one cell at a time, whilst embankment lifting is undertaken in the other cell. All supernatant liquors released by the tailings, plus rainfall runoff from the surface of the TSF would be decanted to the evaporation pond system.

The PAL process would produce about 2.55 Mtpa of tailings, and this would be pumped to the TSF at a solids content of about 48% (ie. approximately 7.6 ML/day of liquor). Based on laboratory testing, it is expected that the tailings would settle to an initial dry density of 1.1 t/m^3. This would result in about 3.2 ML/day of supernatant liquor being released by the tailings, which is expected to flow down the tailings beach to the decant pond. It has been assumed that the TSF would be operated with a nominal decant pond diameter of 300 m under normal operating conditions.

The liquor accompanying the tailings would have a TDS content of approximately 26,600 mg/L, principally consisting of magnesium sulphate ($MgSO_4$) (epsom salts). Calcium sulphate ($CaSO_4$) (gypsum) would be present as a substantial fraction of the solids. The TDS level is too high for the decant liquor to be reused in the process plant or to be treated economically. Approximately 0.48 ML/day of decanted waters would be used for dust suppression on mine haul roads within controlled catchments.

During the evaporation process, magnesium sulphate, aluminium sulphate, calcium sulphate and other sulphates would precipitate and accumulate at the base of the evaporation areas. Periodically these products of crystallisation would be removed and deposited into the TSF.

Experience in the Dead Sea area has shown the deleterious effect of salt (chlorides) on the potential evaporation rate from the free surface, reducing the rate from greater than 90% of pan evaporation to less than 50% at concentrations greater than 30,000 mg/L. However, sulphates do not disassociate to the same degree as chlorides in solution and are thus not expected to result in as dramatic a reduction in the evaporation potential of the liquors.

Magnesium sulphate is expected to reach saturation at approximately 360,000 mg/L, at which concentration it would have the maximum reduction effect on the potential evaporation. Potential variations in the TDS concentrations of the liquor in the TSF and the evaporation areas were modelled in Golder (2000e) to estimate the influence on the efficiency of the evaporation areas.

8.1 TSF WATER BALANCE

A detailed analysis of the TSF water balance has been undertaken, as reported in Golder (2000e), based on the following inputs and outputs.

Inputs into the TSF include:

- Tailings slurry.
- Incident rainfall and tailings beach runoff.

Outputs from the TSF include:

- Heat loss due to the temperature differential between the tailings liquor and the ambient climate.
- Evaporation from the decant pond and active tailings beach.
- Liquors removed to the evaporation ponds.

For the purposes of the water balance modelling presented in Golder (2000e) it has been conservatively assumed that there are no seepage losses from the TSF.

The water balance for the TSF was run over a series of 10 and 30 year sequences using daily rainfall and evaporation data discussed in Section 3.1 of this Appendix. The period between 1970 to 1980 was an extreme wet period with a storm greater than the 1:100 year ARI 72 hour design storm event in early 1976. This period proved to be the most critical 10 year sequence for the TSF and evaporation system, and the results of the water balance modelled over this period of record are presented in Figure 14.

Figure 14 presents a series of graphs, *viz:*

Graph 1.	Rainfall, evaporation and calculated runoff for the TSF. Periods of heavy rainfall occurred in 1974 and 1976, leading to high volumes of runoff.
Graph 2.	Levels of liquor in the TSF decant pond. At no time during the period of analysis does the TSF pond reach the level of the spillway. The TDS of supernatant waters in the decant pond during this period is also shown to be generally at a concentration of 60,000 mg/L, rising during periods of low rainfall to the saturation level of 360,000 mg/L.
Graph 3.	Daily volumes of flow through the decant required to maintain the working depth of the decant pond. This volume rises to a maximum of approximately 240 ML/day during the early 1976 rainfalls, but averages at the supernatant rate of approximately 2.3 ML/day (Figure 15).

The remaining graphs on Figure 14 relate to the operation of the evaporation ponds (Section 8.2).

8.2 EVAPORATION PONDS AND SURGE DAM WATER BALANCE

The excess water decanted from the TSF would be transferred to the evaporation system (Figures 2 & 13) comprising:

- 7 shallow evaporation ponds over an area of 121 ha.
- 56 ha evaporation surge dam, divided into 4 evaporation ponds.

The inputs into the evaporation area would be decant water and seepage from the TSF and rainfall. Evaporation would be the only modelled loss from the evaporation system. For the purposes of the water balance modelling presented in Golder (2000e) it has been conservatively assumed that there are no seepage losses from the evaporation ponds or surge dam.

The water balance for the evaporation ponds and surge dam has been integrated with the TSF water balance, and includes the daily liquor reuse rate of 0.48 ML/day. The assumed operating depths for the evaporation ponds, the surge dam evaporation ponds and the surge dam (maximum operating depth) are 2.5 m, 2 m and 7 m respectively. The results of the analysis for the 1970 to 1980 period extreme wet 10 year sequence are shown in Figure 14.

Graph 4. The evaporation ponds fill rapidly after startup, reaching an operating depth of approximately 2.2 m within 12 months. Thereafter, there are nearly year long periods when the evaporation ponds operate at their maximum depth and excess water would be transferred to the surge dam. During dry years the liquor level in the evaporation ponds drops well below their maximum operating depth.

The TDS concentration in the evaporation pond increases to approximately 200,000 mg/L and remains between 100,000 and 200,000 mg/L for most of the period analysed. This variation is due to the flushing effect of the rain falling on the evaporation ponds and the decant flows during wet periods.

Graph 5. The transfer rate to the surge dam is at zero for long periods and rises to 75 ML/day during short periods of very heavy rain.

Graph 6. Very little liquor is transferred to the surge dam during the first four years, while the evaporation ponds fill. Subsequently, the liquor level in the surge dam remains at about half depth, over 500 mm below the spillway level even during the heavy rainfall periods in 1976. The salt level in the surge dam rises to saturation (360,000 mg/L) after five years of operation and would likely remain at these concentrations for the remainder of the Project.

Graph 7. For all of the rainfall events modelled, the surge dam did not overflow during the life of the facility. The rainfall data for this period included a 220 mm 72 hour rainfall event in 1976, which exceeds the estimated 180 mm generated from the 1 in 100 year 72 hour design storm event.

Additional analyses were undertaken for 30 and 40 year sequences from 1970 to 2000, 1940 to 1970 and 1900 to 1940. As there is no evaporation data prior to 1970, monthly evaporation for these runs were estimated by correlation with the recorded monthly rainfall. There was no system overflow during the 100 years of historical record modelled. The modelled periods exceed the expected operational life of the TSF and evaporation system.

8.3 FINDINGS

An extensive water balance analysis was conducted for the proposed TSF and evaporation pond system using established analysis principles and historical data appropriate for the site. The results of this analysis indicate:

- No spillage is likely to occur from the TSF, evaporation ponds or evaporation surge dam during the life of the facilities, based on modelling for the 100 year period.
- The TSF cells, evaporation ponds and surge dam would be maintained at all times with sufficient freeboard to contain the runoff generated from the 1 in 100 year ARI rainfall event of 72 hours duration.

9 SURFACE WATER DIVERSIONS

An assessment of the hydraulics of the proposed northern and southern diversions (Figure 2) and the estimated magnitude of potential surface water flows likely to be generated from their catchments is presented in Golder (2000c).

This section presents a summary of the findings of Golder (2000c).

9.1 DESIGN FLOWS

100 year ARI flows were used as the design criteria for the surface water diversions. Design flows for the northern and southern diversion channels were investigated using a RAFTS[5] model of the mine site catchment (Golder, 2000c). Storm durations from 1 to 12 hours were investigated. Durations typically in the range of 3 to 6 hours were found to generate the highest flows.

9.1.1 Diversion Sizing

The preliminary sizing of the diversion channels was based on a uniform flow analysis at peak discharge (Manning's equation) for the northern and southern diversions. The location of the diversion channels is shown on Figure 2.

Channel sections were selected to cater for the calculated flow depths. Broad flat-battered channels were favoured to reduce the flow energy dissipated per unit area, and hence the scour potential if the flow is well distributed across the channel section. The preliminary sizing for these channels, all with 3(V):1(H) embankment slopes and retaining a 400 to 500 mm freeboard, are presented in Golder (2000c) and summarised in Table 12.

Table 12
Preliminary Diversion Sizing

Diversion Location	Generalised Channel Slope	100 Year ARI		Channel Depth m	Base Width m	Flow Velocity m/s
		Peak Flow m³/s	Flow Depth m			
Northern diversion north branch	1:500	17	1.1	1.5	10	1.2
Northern diversion south branch	1:330	20	1.1	1.5	10	1.4
Northern diversion central section	1:330	37	1.25	1.7	15	1.6
Northern diversion lower section	1:130	58	1.24	1.7	15	2.5
Southern diversion upper part	1:300	21	1.1	1.5	10	1.5
Southern diversion lower part	1:130	21	0.85	1.5	10	2

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[5] XP-RAFTS Version 4 from XP-Software

Most of the lengths of the channels would be expected to function adequately as grassed waterways.

The lower 1 km of the northern and southern diversion channels have average slopes of the order of up to 1(V) in 130 (H). These sections are likely to need some scour protection hardening, such as crushed rock (riprap) placed over a geotextile filter. With time it is expected that these sections of channel would become well grassed.

10 ASSESSMENT OF POTENTIAL HYDROGEOLOGICAL IMPACTS

This section is a summary of the reports *Regional and Local Hydrogeological Impacts of the Proposed Syerston Nickel Mine Fifield, NSW* (Golder, 2000a) and *Hydrogeological Impacts of the Tailings Storage Facility of the Proposed Syerston Nickel Mine Fifield, NSW* (Golder, 2000g). The objectives of these studies were to describe the regional hydrogeology and assess potential hydrogeological impacts that may arise from the operation of the proposed TSF. The work conducted as part of these studies included:

- Assessment of the hydrogeological conditions surrounding the mine site.
- Assessment of the potential impacts of the TSF and evaporation system on the regional and local hydrogeology.
- Development of mitigation and control measures to reduce potential hydrogeological impacts of the Syerston Project.

Section 3 of this Appendix provides a description of environment including the interpreted hydrogeological regime.

10.1 GROUNDWATER MODEL

Groundwater modelling was carried out for a section under the TSF and evaporation ponds to investigate the potential development over time of seepage from the base of these facilities. A representative hydrogeological cross section, developed from the results of the hydrogeological drilling programme (Section 4), is shown on Figure 5 and its location is shown on Figure 4.

The modelling was performed in stages using the computer programme SEEP-W. SEEP-W is a numerical modelling package that simulates 2 dimensional variably-saturated groundwater flow. The model can simulate groundwater flow in the partially saturated zone above the water table, and saturated flow below the water table.

The model was used to examine the range of seepage rates which could develop from the TSF and evaporation ponds, for the likely range in hydraulic parameters and various pond/storage construction and operation scenarios.

The model layering was based on a generalisation of the subsurface conditions interpreted to exist from the results of site investigations and the hydrogeological testing programme (Section 4), and shown on Figure 5. The following layering (from top to bottom) was used to represent the subsurface conditions:

- Surface alluvium.
- Very weathered rock.
- Moderately weathered rock.
- Basement rock.

Due to an apparent similarity in the hydraulic parameters (in particular hydraulic conductivity), the palaeochannel materials were represented by the same material types, without basement rock. The estimated outline of the palaeochannel is indicated on Figure 5.

10.1.1 Assumptions, Parameters and Boundary Conditions

The finite element mesh and boundary conditions adopted for the groundwater modelling are presented in Golder (2000a). In summary, the following boundary conditions were adopted:

- A constant head boundary at the ground surface in the area of the evaporation ponds, representing water in the ponds at an elevation of RL 282 m AHD;
- Constant head boundaries along the vertical model boundaries at the right and left hand extremities of the model. The constant heads defined for these boundaries were based on measured water levels in these areas. Constant head boundaries assume that groundwater levels at that location would not be affected by the operation of the TSF or evaporation ponds.

Boundary conditions in the area of the TSF were altered for each stage of modelling. Details of the functional relationships between suction pore pressures and hydraulic conductivity adopted for the modelling are presented in Golder (2000a). A summary of the hydraulic parameters used in the model is provided in Table 13.

The total length of the model section is 5.5 km, which was necessary to cover the TSF, evaporation ponds and the palaeochannel mapped to the north-west of these facilities. The base of the model was set about 200 m below the surface, representing the assumed level below which there would be no hydrogeological impacts arising from operation of the storage facilities.

Table 13
Summary of Hydraulic Parameters used in Model

Depth Interval (m)	Material	Dry Conditions			Saturated Conditions			Specific Yield[2] %
		Pore Pressure kPa	Volumetric Water Content %	Hydraulic Conductivity[1] m/s	Pore Pressure kPa	Volumetric Water Content %	Hydraulic Conductivity[1] m/s	
0 to +30	Tailings	-40	10	3×10^{-6}	≥0	39	3×10^{-6}	29
0 to 3	Alluvial Soil	-60	25	1×10^{-6}	≥0	40	1×10^{-6}	15
3 to 25	Very Weathered Rock	-30	30	1×10^{-8}	≥0	35	1×10^{-8}	5
25 to 50 (variable)	Moderately Weathered Rock	-30	34.5	1×10^{-8}	≥0	35.5	1×10^{-8}	1
50 to 250	Basement Rock	-30	34.5	1×10^{-8}	≥0	35.5	1×10^{-8}	1

[1] Hydraulic conductivity was assumed to be isotropic for all materials except tailings. The value specified above for tailings represents horizontal hydraulic conductivity, and a value 10 times less than this was adopted for vertical hydraulic conductivity.

[2] Specific yield represents the volume of water which would be released from storage due to a unit decrease in water level, in a unit volume of porous medium.

10.1.2 Modelled Tailings Placement

The model was used to simulate the placement of tailings over a period of 20 years, followed by the capping of the TSF with a low-infiltration surface treatment. The gradual increase in height of tailings was represented in 6 discrete stages as indicated in Table 14.

For each of the main modelling stages (Steps 1 to 6), the application of tailings was modelled in two parts:

Part A – Placement of new tailings with constant head (zero pressure) boundary conditions at all nodes in the newly placed tailings, in order to establish saturated conditions within this material. Constant head boundary conditions were maintained for a period of 2 days at the start of each of the 6 modelling stages.

Part B – Change boundary conditions such that constant head conditions are applied only over the area of the decant pond. Outside of this area, the drainage of the saturated surface tailings to the underlying material is simulated by the model.

These conditions were maintained for the remainder of each modelling stage.

Table 14
Summary of Modelling Sequence

Modelling Run	Height of Tailings m	Length of Simulation yrs	Cumulative Total Time yrs
Base	Nil	Steady State	Start
Step 1	5	1	1
Step 2	10	3	4
Step 3	15	4	8
Step 4	19	5	13
Step 5	23	4	17
Step 6	27.5	3	20
Closure	27.5	30	50

10.1.3 Modelled Seepage Controls

A low permeability clay liner would be constructed under the TSF cells, evaporation ponds and the surge dam, by compacting the in-situ clay material to a depth of 1 m (Golder, 2000f). Laboratory testing has indicated that the in-situ clay material would achieve a permeability of less than 1×10^{-9} m/s.

A toe drain would be installed to intercept seepage through the tailings and near ground seepage in the soils under the TSF (Section 6.2). The toe drain would control the level of the phreatic surface within the tailings.

10.1.4 Modelled Seepage Water Quality

The TDS of the seepage water is expected to be similar to the incoming tailings slurry with a TDS of approximately 26,600 mg/L. The dominant dissolved salt would be magnesium sulphate.

10.2 RESULTS

Results of the seepage analysis are presented in Golder (2000a), including:

- Estimates of seepage fluxes (flow rates) through the base of the tailings storage area and the base of the evaporation pond.
- Estimates of lateral velocities of groundwater seepage from the TSF in a north-west direction and from the evaporation ponds in a south-east direction, in the moderately weathered rock sequence.
- Simulations of the water table position over time.

Table 15 summarises the results of the seepage modelling.

Table 15
TSF and Evaporation Pond Seepage Predictions

Average Seepage Rate: TSF m^3/day	Average Seepage Rate: Evaporation Ponds m^3/day	Seepage Migration beyond Footprint @ 50 years m
250	90	825 m NW / 775 m SE

10.2.1 Groundwater Flux

Predicted rates of seepage through the base of the facilities are expected to reduce significantly with time, for the following reasons:

- High initial soil suction values create an initially high hydraulic gradient. As the saturation of underlying soils and rock increases, and suction decreases, the corresponding flow rate decreases.
- Velocity of flow decreases for a constant flux as the perimeter of the wetting front increases.
- As the height of the TSF increases, the hydraulic resistance to seepage from the decant pond increases, resulting in decreased vertical flow. The model takes no account of the effect of decreasing permeability of the tailings with time as consolidation occurs.

The total fluxes through the base of the TSF can be compared to the total anticipated input of water. The total flux through the base of an unlined TSF is estimated to be about 9% of the total tailings liquor input for a 20 year period. The development of an *insitu* clay liner is predicted to reduce total flux from around 5,300 ML to about 4,600 ML, representing a reduction in the volume of total seepage of 15%.

The estimated distances of seepage migration beyond the footprint of the storage facilities at 50 years after commencing mine operations are provided in Table 15. These values are considered to be conservative upper values because the model takes no account of the probable effect of decreasing permeability of the tailings with time as consolidation occurs. This effect would be most significant at the base of the tailings storage facility, with the effect of further reducing the rate of seepage.

10.2.2 Seepage Front and the Watertable

Modelling indicates that a groundwater mound would develop within approximately 8 years. No surface break-out of the water table before the end of mine operations is predicted. The water table is expected to drop away sharply from the external footprint of the storage facilities.

When tailings disposal ceases, the groundwater table is predicted to dissipate slowly, spreading in area as its height falls. At 50 years, the groundwater table is predicted to come close to the ground surface (within about 5 to 10 m depth) in the zone between the two storage facilities, and some surface break-out is predicted to occur within approximately 50 m of the footprint.

10.2.3 Groundwater Mounding

The seepage modelling predicts that the groundwater would generate a mound between the TSF and the evaporation ponds over a period of 15 years. Additional monitoring bores would be located in this area to monitor its development (Figure 16). If the groundwater mound rises above a level 15 m below the ground surface, it may be necessary to install a set of dewatering bores to control its rise. If these dewatering bores were installed, any water recovered would be discharged into the evaporation ponds.

10.3 POTENTIAL HYDROGEOLOGICAL IMPACTS

10.3.1 Local Groundwater System

The hydrogeological assessment presented in Golder (2000a) indicates:

- Gradual saturation of the soils underlying the TSF and evaporation ponds over a 5 year period following commencement of tailings deposition and storage of decanted waters in the evaporation ponds.
- Lateral spreading of the groundwater mound, with rises in the water table elevation extending to distances estimated to be up to a maximum of 825 m from the TSF and evaporation pond footprint.

Development of the seepage front may occur more rapidly in zones where the rock permeability is higher, but these zones are expected to be limited.

10.3.2 Regional Groundwater System

A description of the regional hydrogeology is presented in Section 3.3. The site specific investigations and seepage modelling undertaken as part of Golder (2000a) have indicated the following:

- The potential for seepage of liquor from the TSF and evaporation ponds is constrained by the low permeabilities in the underlying and adjacent soil and rock, and also the maximum height of saturated tailings and depth of water in the proposed evaporation ponds.
- Beyond the zone of raised groundwater velocities induced by the operation of the TSF, the groundwater system is inferred to have very low to low velocities. The estimated regional groundwater velocity of 0.1 m/year is equivalent to 100 m per 1,000 years. The localised groundwater mound associated with the TSF and evaporation ponds is expected to dissipate in the order of 50 to 150 years from cessation of operations.

- The regional survey did not locate any groundwater use within 5 km down-gradient of the site.
- Local groundwater quality in the vicinity of the site has been measured to be saline.

10.4 MONITORING

Seepage performance and the potential effect that the TSF and evaporation areas have on the groundwater table would be monitored with a network of monitoring bores (Figure 16). A number of bores already exist for background monitoring purposes, and the installation of four additional bores is recommended prior to commencement of operations.

Monitoring bores should be measured for water levels and sampled on a monthly basis during the first few years of operation. Thereafter, sampling could be reduced to approximately twice per year.

If the monitoring bores indicated that the rate of change in water table levels was greater than expected, or that the conditions differ from those predicted, additional monitoring bores would be installed to provide further information. If necessary, these bores could be used as pumping bores to control the migration of seepage.

11 REFERENCES

Australian and New Zealand Environment and Conservation Council (ANZECC) 1992. *Australian Water Quality Guidelines for Fresh and Marine Waters.*

Australian Bureau of Meteorology (1989) *Climate of Australia*.

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Golder Associates Pty Ltd (2000b) Geotechnical Investigation for the Tailings Storage Facilities - Syerston Nickel Project. Report prepared for Black Range Minerals.

Golder Associates Pty Ltd (2000c) Surface Water Hydrology and Diversion Works - Syerston Nickel Project Fifield, New South Wales. Report prepared for Black Range Minerals.

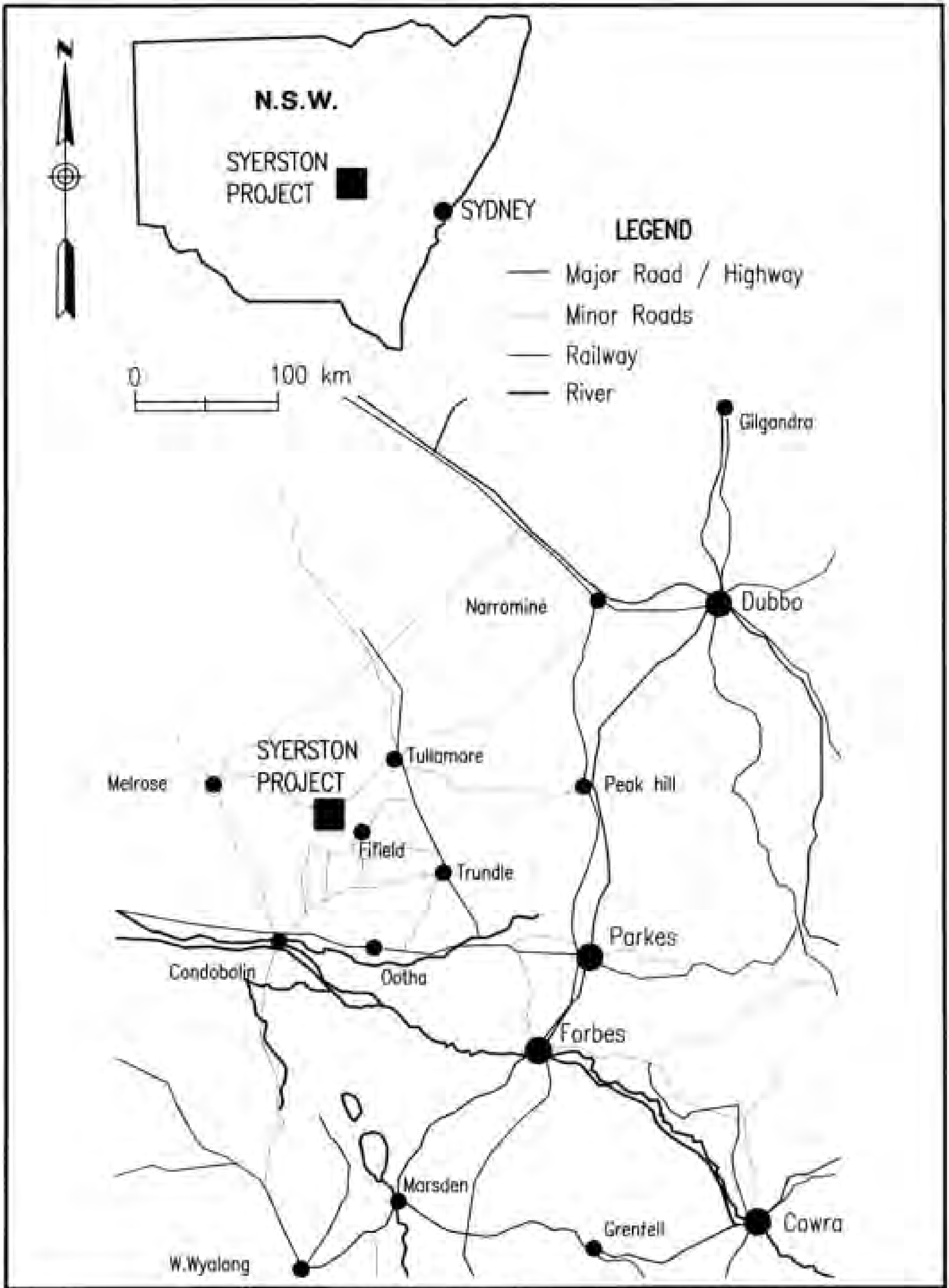
Golder Associates Pty Ltd (2000d) Geotechnical Investigation for the Plant Site, Mine Pits and Limestone Quarry - Syerston Nickel Project Fifield, New South Wales. Report prepared for Black Range Minerals.

Golder Associates Pty Ltd (2000e) Tailings Storage Water Balance - Syerston Nickel Project Fifield, New South Wales. Report prepared for Black Range Minerals.

Golder Associates Pty Ltd (2000f) The Preliminary Design of the Tailings Disposal Facility for the Syerston Nickel Project. Report prepared for Black Range Minerals.

Golder Associates Pty Ltd (2000g) Hydrogeological Impacts of the Tailings Storage Facility of the Proposed Syerston Nickel Mine Fifield, NSW. Report prepared for Black Range Minerals.

FIGURES



Golder Associates

CLIENT BLACK RANGE MINERALS N.L.		PROJECT SYERSTON NICKEL PROJECT	
DRAWN LMB	DATE 08-12-99	TITLE LOCATION MAP	
CHECKED NG	DATE 3/00		
SCALE NOT TO SCALE	A4	PROJECT No 99631001-F-11	Figure 1

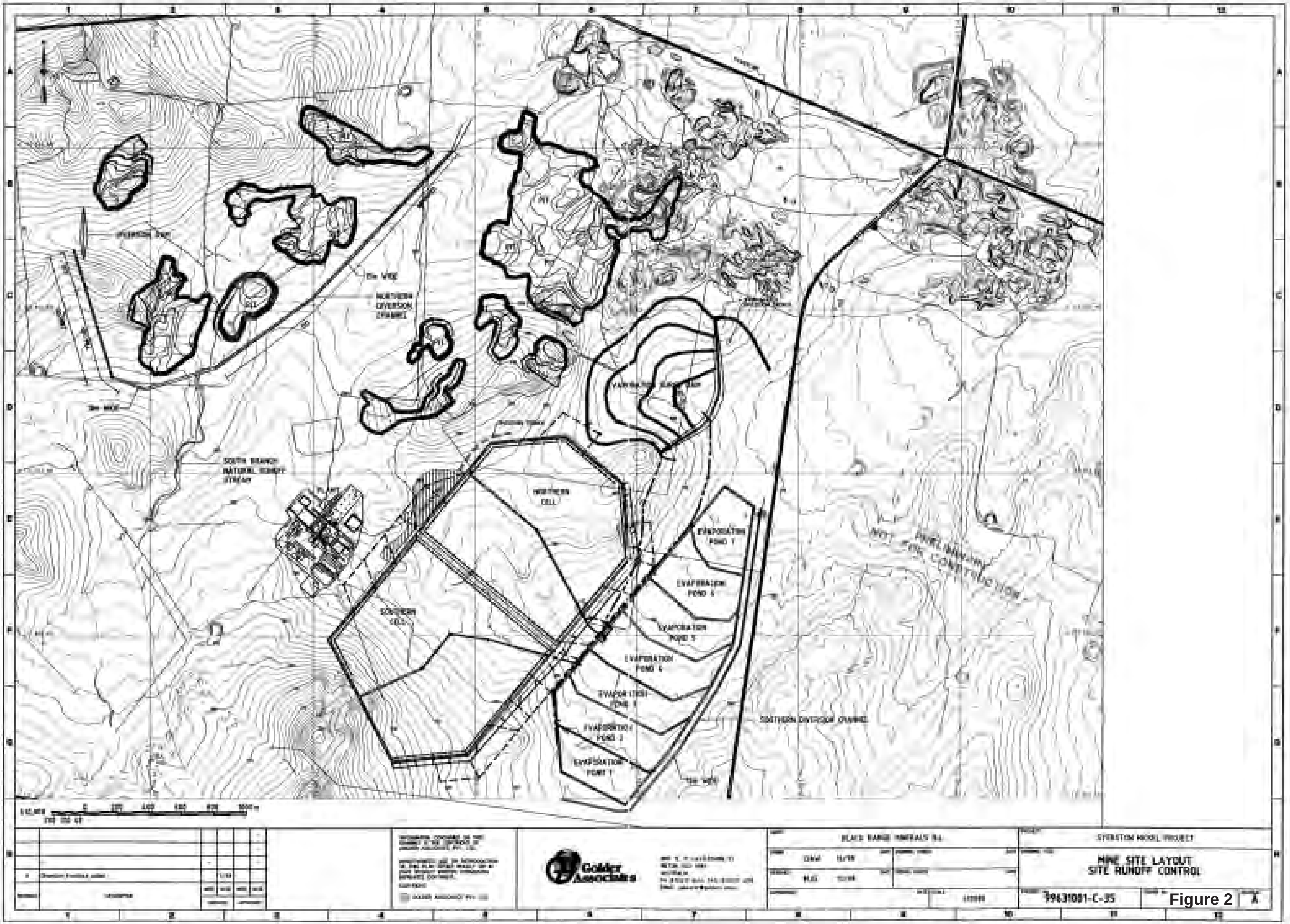
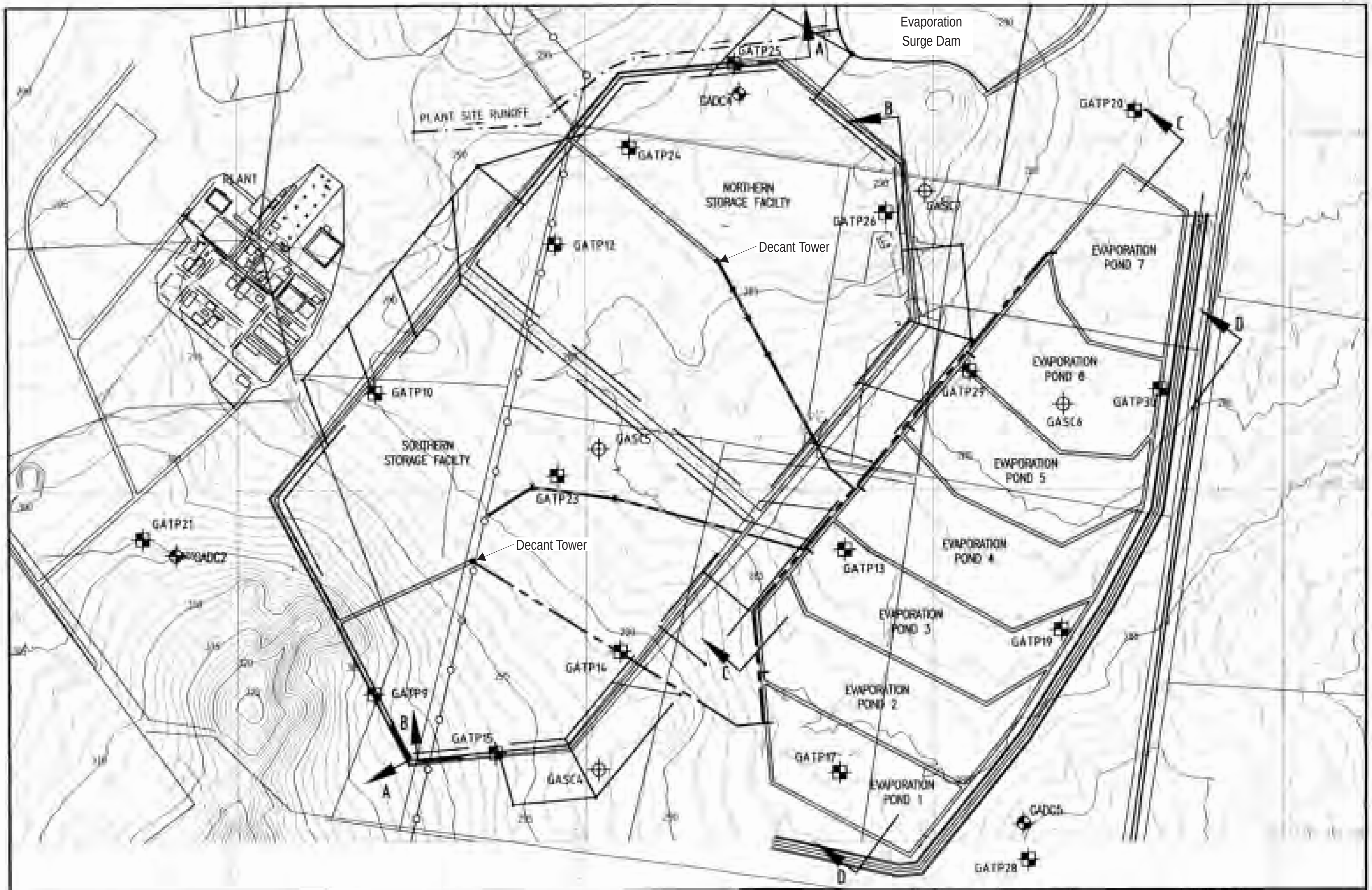

NORTHERN DIVERSION CHANNEL
15m WIDE
SOUTH BRANCH NATURAL RUNOFF STREAM
NORTHERN CELL
SOUTHERN CELL
EVAPORATION POND 7
EVAPORATION POND 6
EVAPORATION POND 5
EVAPORATION POND 4
EVAPORATION POND 3
EVAPORATION POND 2
EVAPORATION POND 1
SOUTHERN DIVERSION CHANNEL
PRELIMINARY NOT FOR CONSTRUCTION
BLACK RANGE MINERALS N.L.
SYERSTON NICKEL PROJECT
MINE SITE LAYOUT
SITE RUNOFF CONTROL
99631001-C-35
A
Golder Associates

Figure 2



LEGEND
- ▣ Test Pit
- ⊕ Deep Cored Borehole
- ⊕ Shallow Cored Borehole

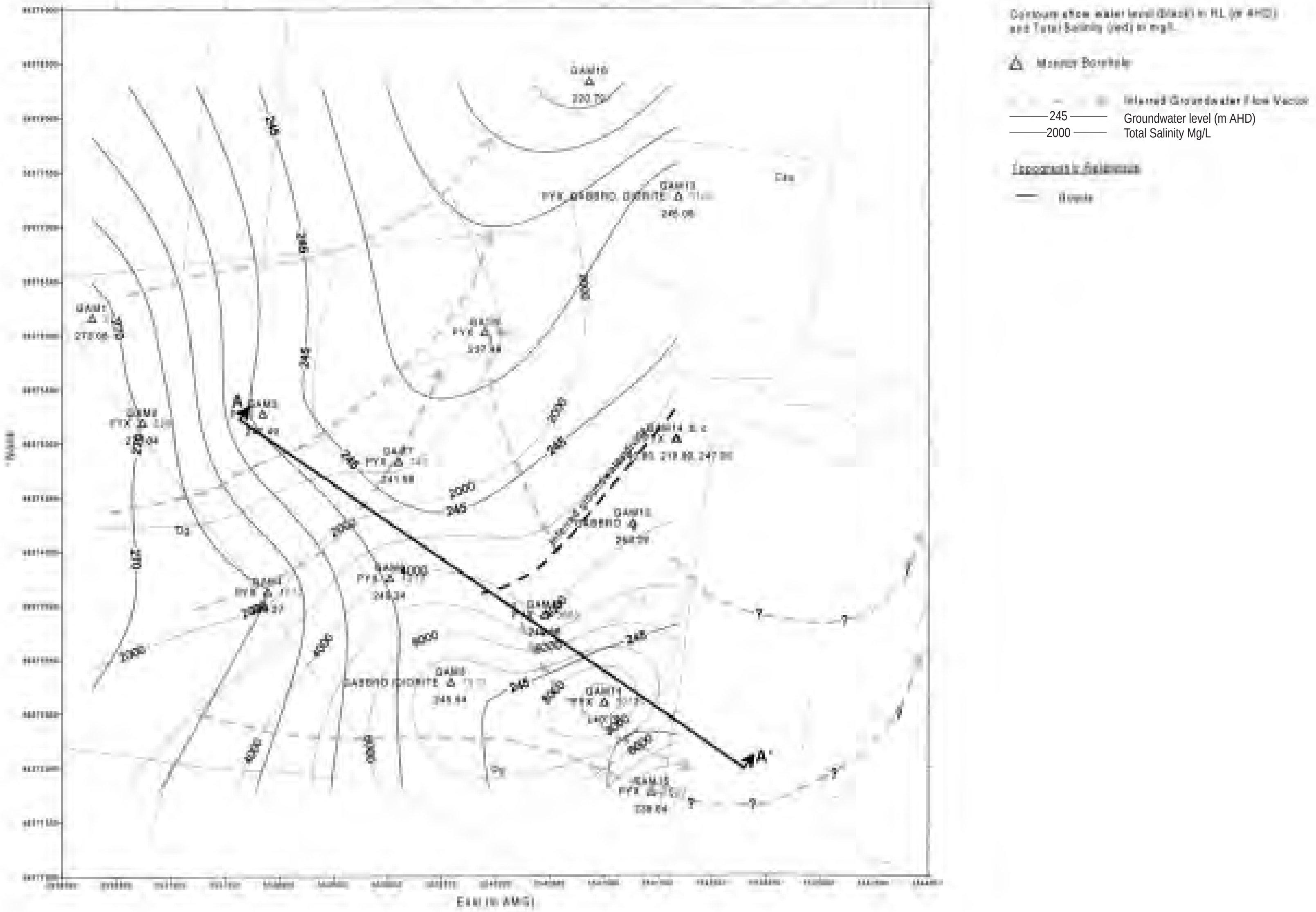
Golder Associates

T.M.O.	08-12-99
	3/4/00
1 : 1000	A3

BLACK RANGE
SYERSTON NICKEL
SITE INVESTIGATION LOCATION PLAN

99631001-8-16

Figure 3



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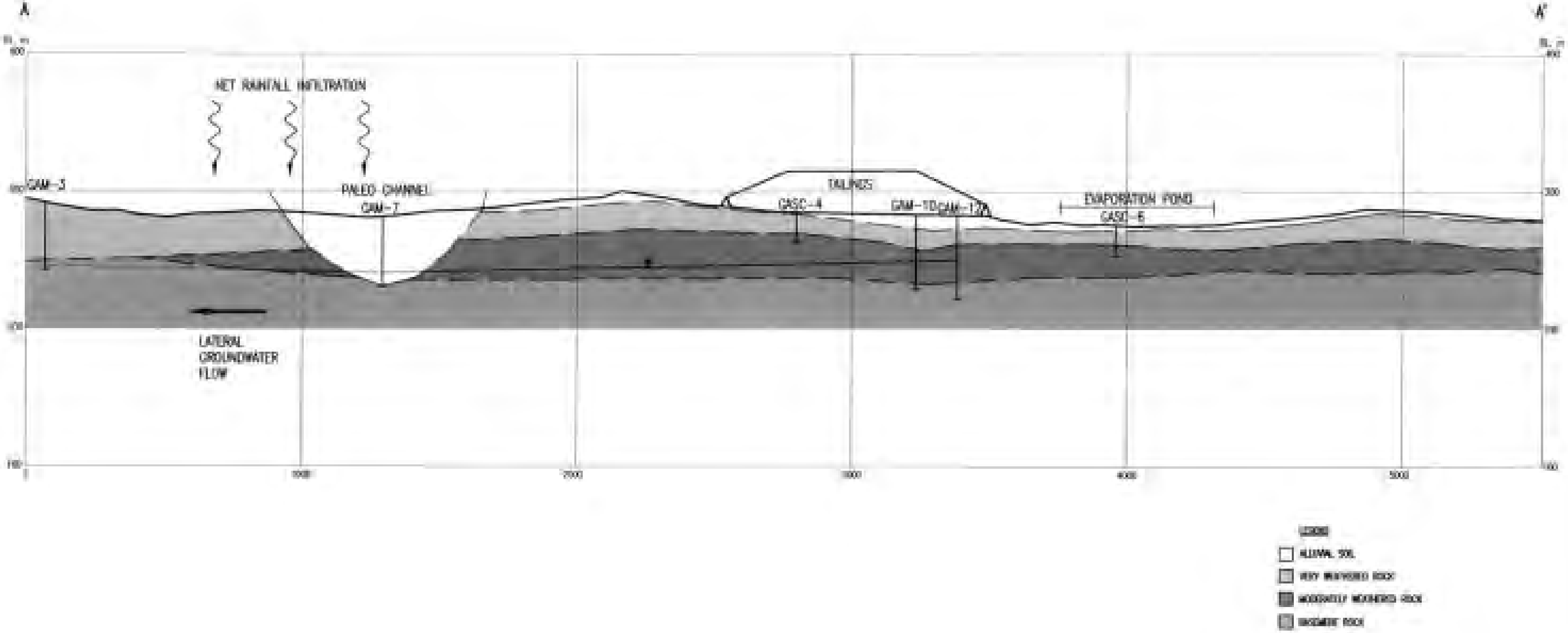
DRAWN LHJ	DATE AUGUST 1999	TITLE SITE HYDROGEOLOGY
CHECKED	DATE 24/3/00	
SCALE AS SHOWN	A3	PROJECT No 99631001 — Figure 4

Golder Associates



BLANK RANGE MINERALS, N.L.

SYERSTON NICKEL PROJECT

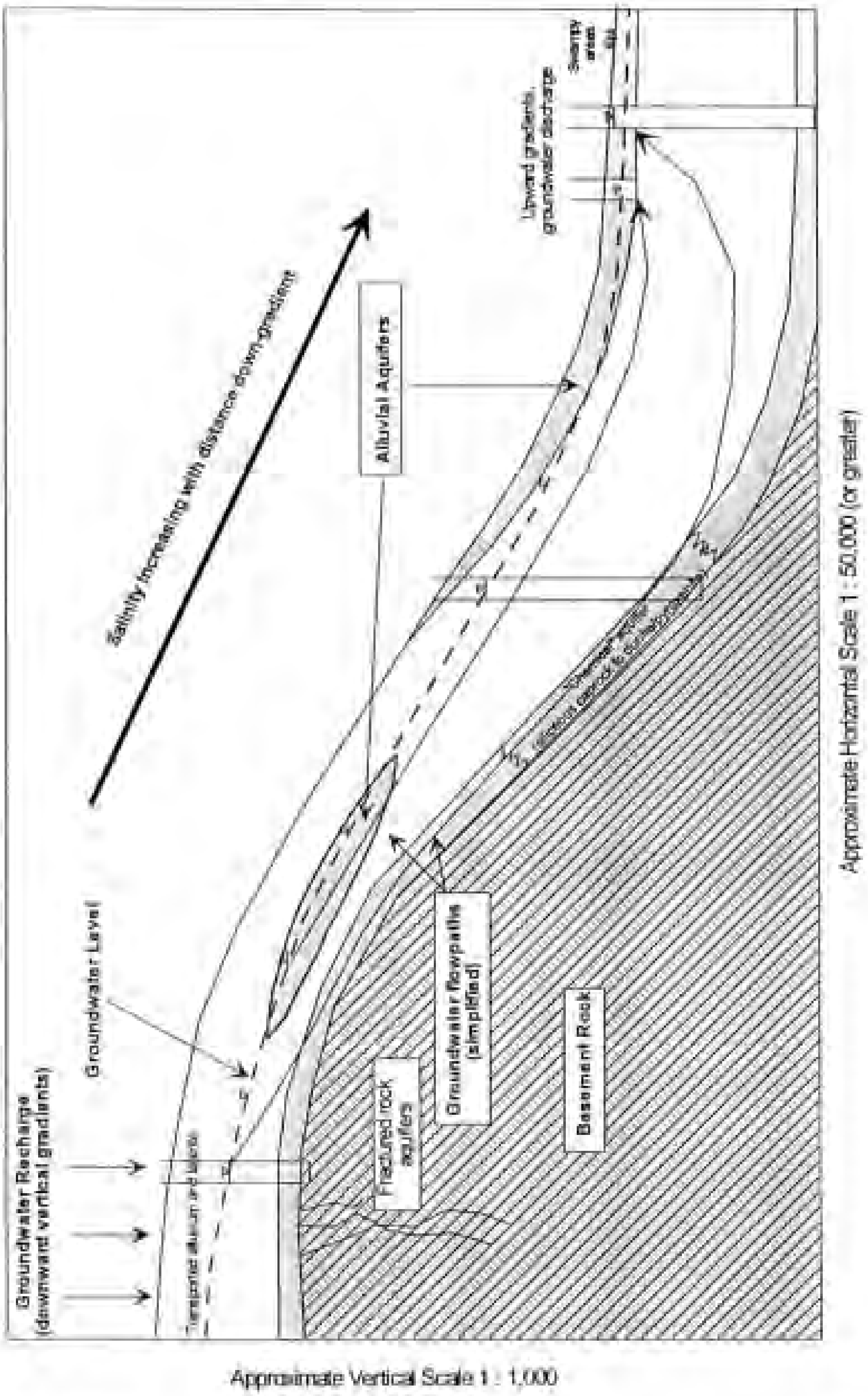
LMB 23-03-00

GROUNDWATER MODELLING REPRESENTATIVE HYDROGEOLOGICAL CROSS SECTION

NOT TO SCALE A3

99631001-8

Figure 5



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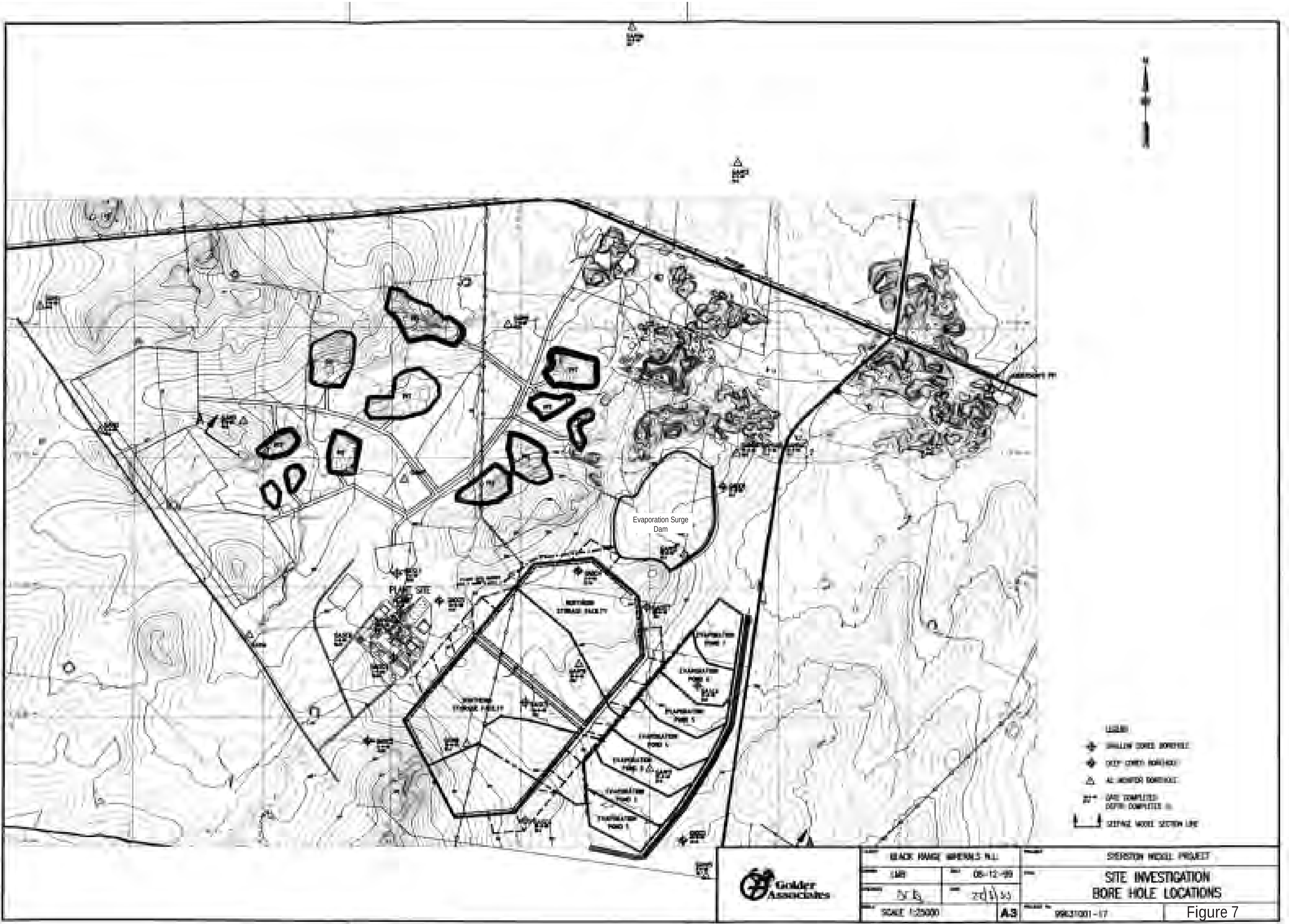
	DRAWN SCD	DATE Dec 1999	TITLE Conceptual Regional Hydrogeological Cross Section	
	CHECKED AUH	DATE 28/2/00		
	SCALE As Shown	A4	PROJECT No 99631001	Figure 6

BRM-98-01-WM_004A



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BLACK RANGE MINERALS N.L.

LMB 08-12-99

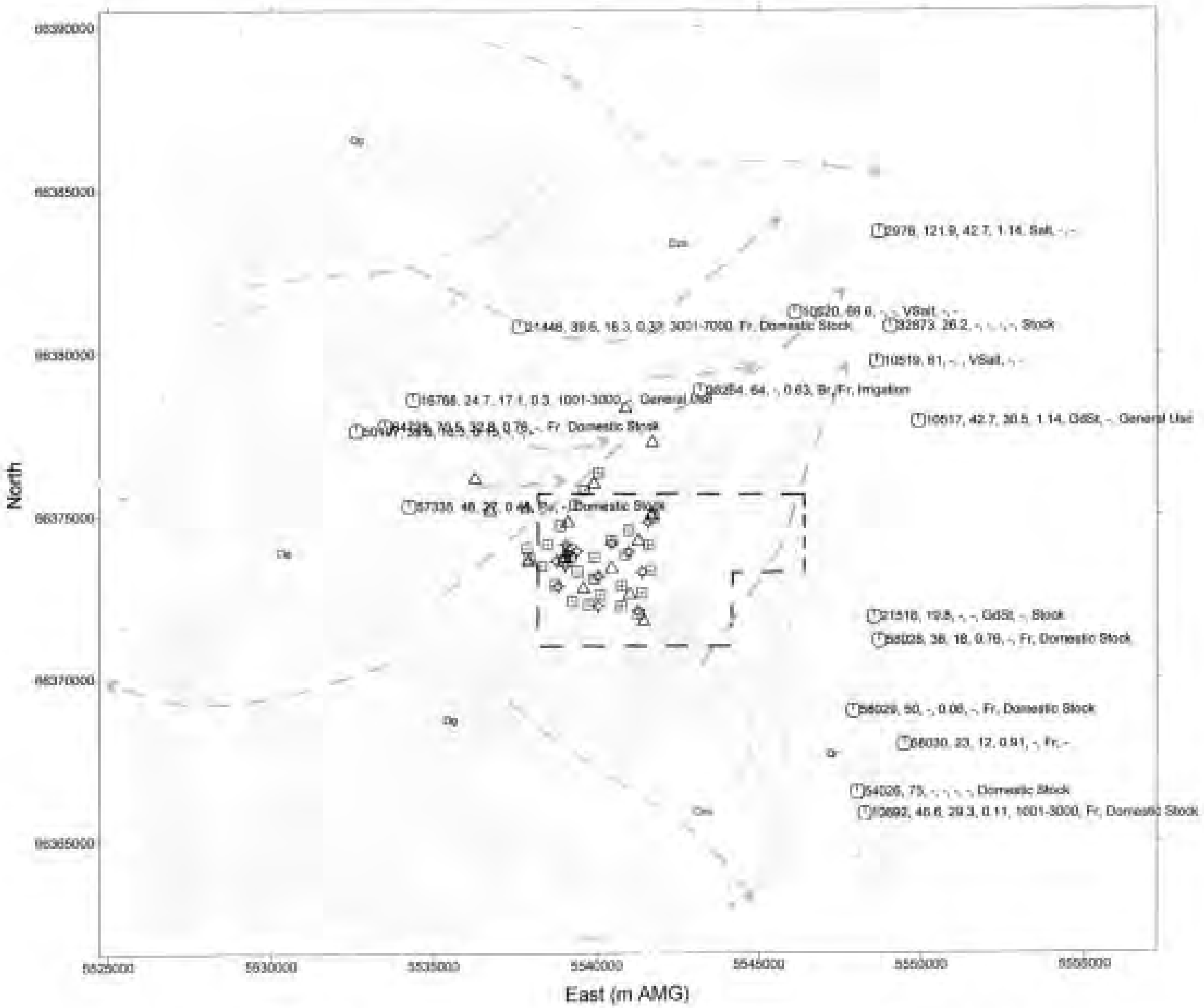
SCALE 1:25000 A3

SYERSTON NICKEL PROJECT

SITE INVESTIGATION
BORE HOLE LOCATIONS

99631001-17

Figure 7



Borehole, Total Depth (m), [illegible]
Test Pit
Cored Borehole
Monitor Borehole

Topographic Reference
Roads
[illegible]

Geological Reference
[illegible]

Golder Associates	Black Range Minerals		SYERSTON REGIONAL HYDROGEOLOGY
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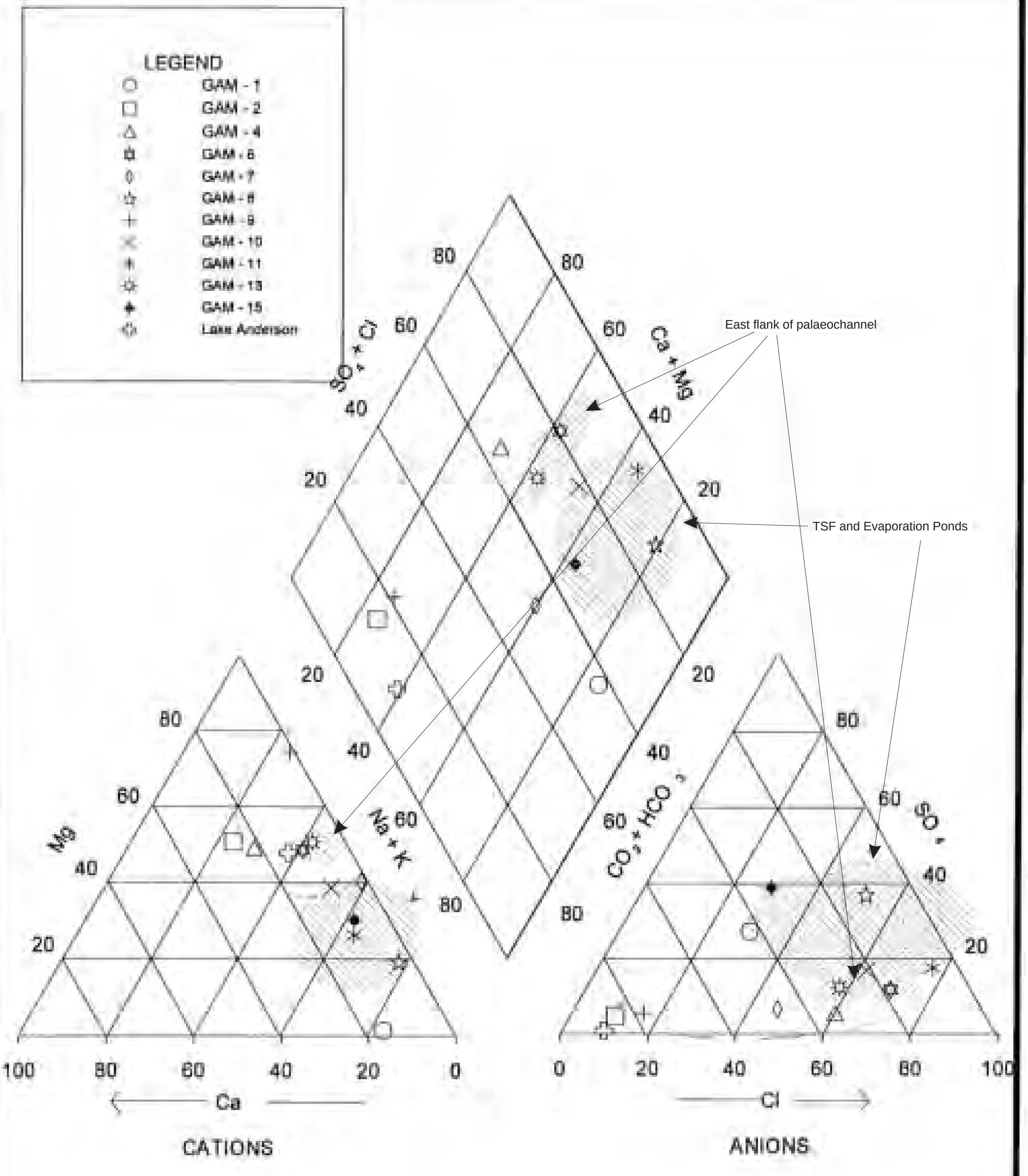
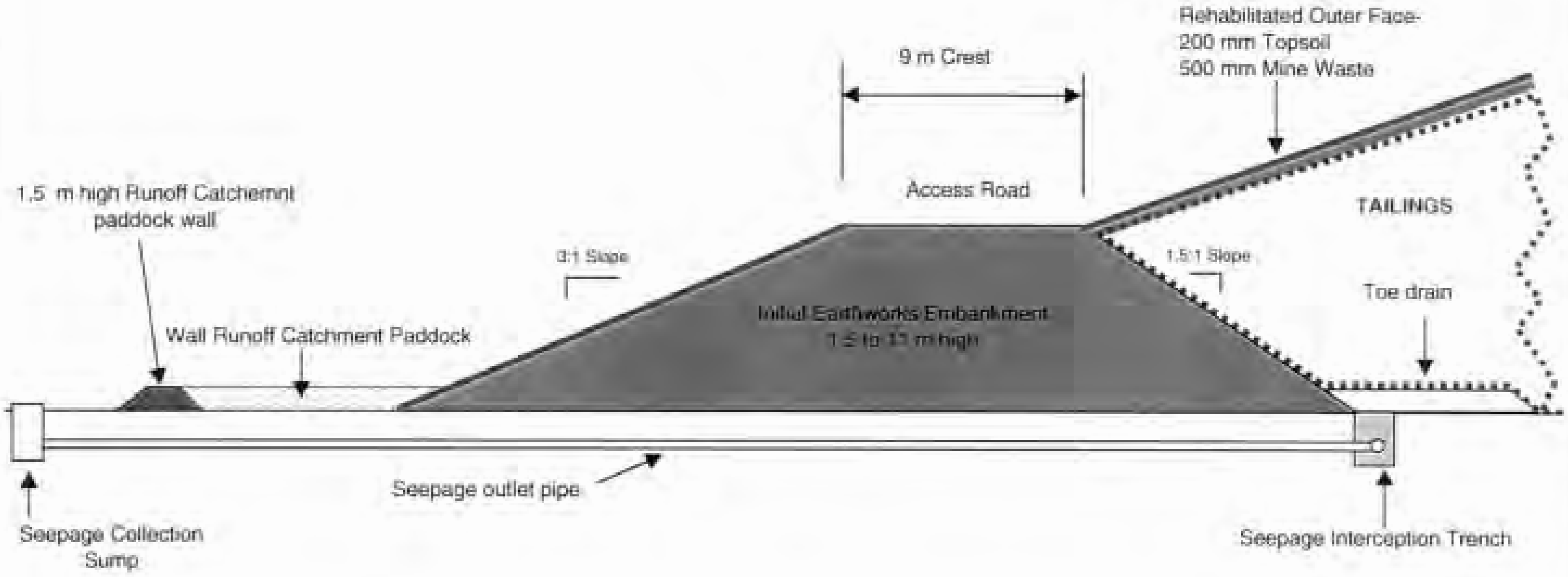
	AS SHOWN	A3	99631001 — Figure 8



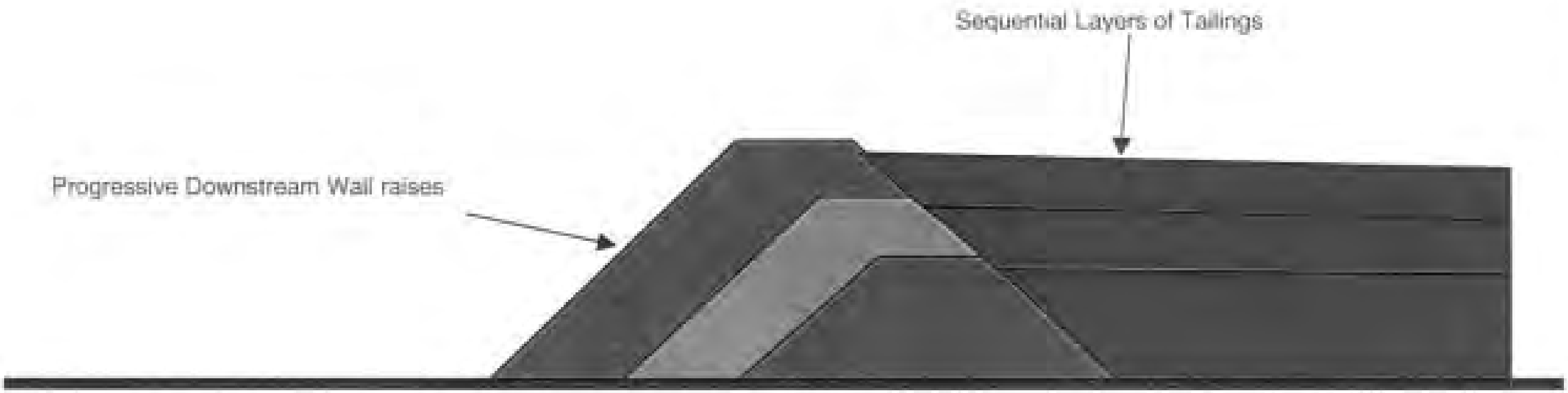
CLIENT Black Range Minerals		PROJECT Syerston
DRAWN	DATE October 1999	TITLE **PIPER DIAGRAM**
CHECKED	DATE	
SCALE As Shown	A4	PROJECT No 99631001 — Figure 9

Golder Associates

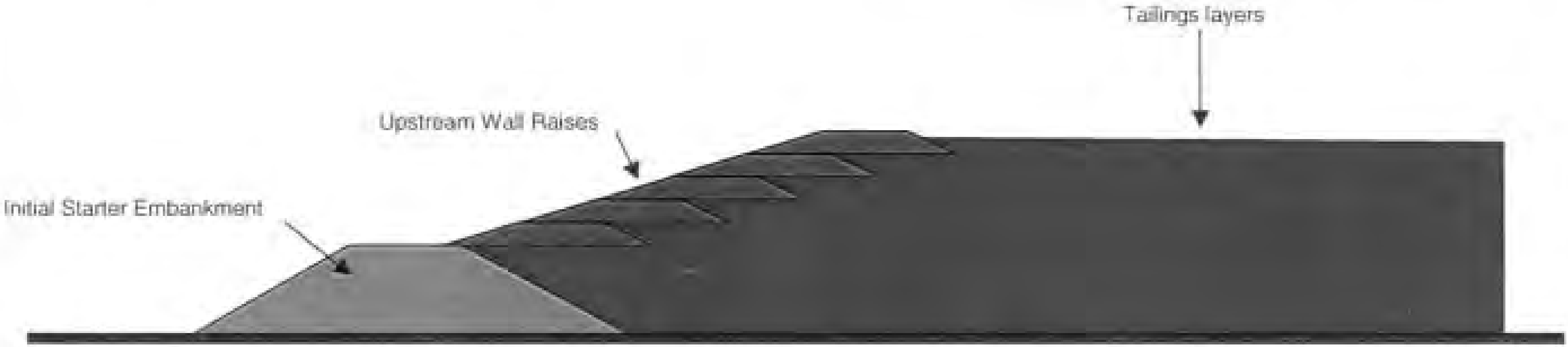


Golder Associates

CLIENT	BLACK RANGE			PROJECT	SYERSTON NICKEL
DRAWN	lb	DATE	02/12/00		Typical Section through Intial Embankment & Toe Drain
CHECK	mjg	DATE	Feb-00		
SCALE	nts		A4	PROJECT No. 99631001-F	Figure 10



TYPICAL DOWNSTREAM WALL RAISING

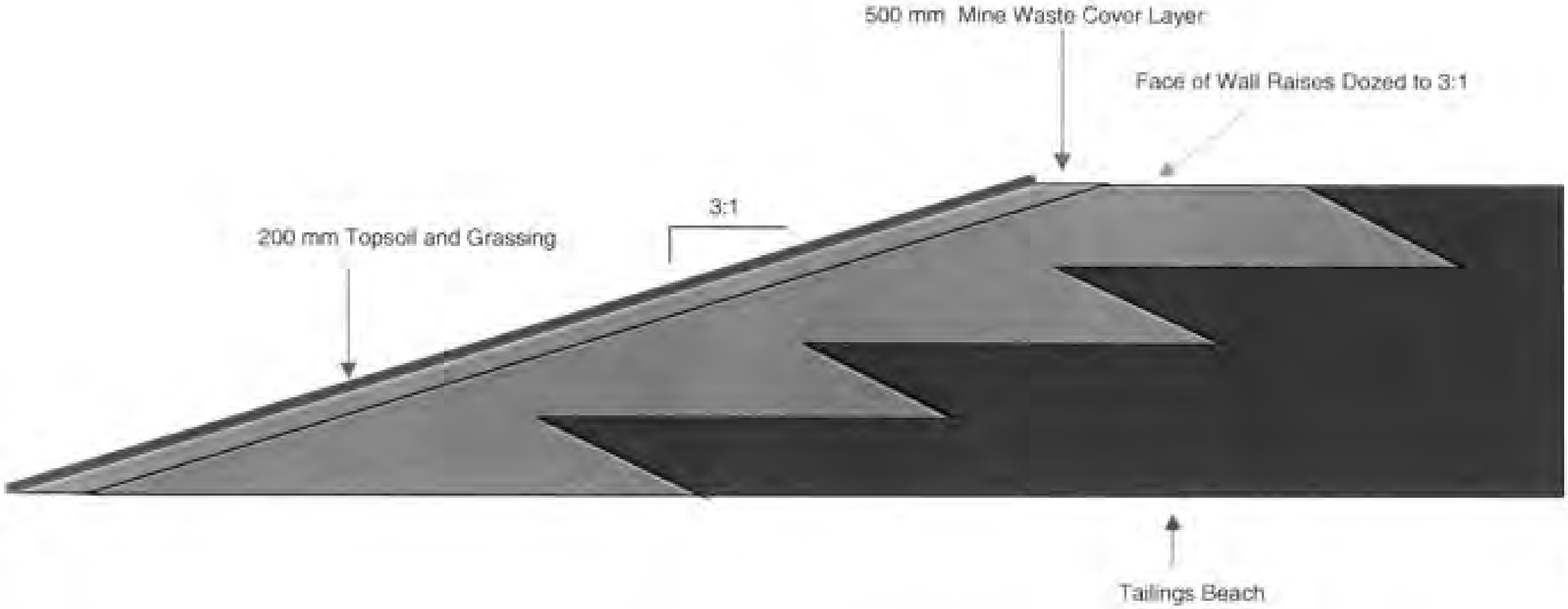


TYPICAL UPSTREAM WALL RAISING

Golder Associates

CLIENT	BLACK RANGE			PROJECT	SYERSTON NICKEL
DRAWN	lb	DATE	02/12/00	Comparison of Downstream and Upstream Wall Rasing Systems	
CHECK	mjg	DATE	Feb-00		
SCALE	nts		A4	PROJECT No. 99631001-F	Figure 11

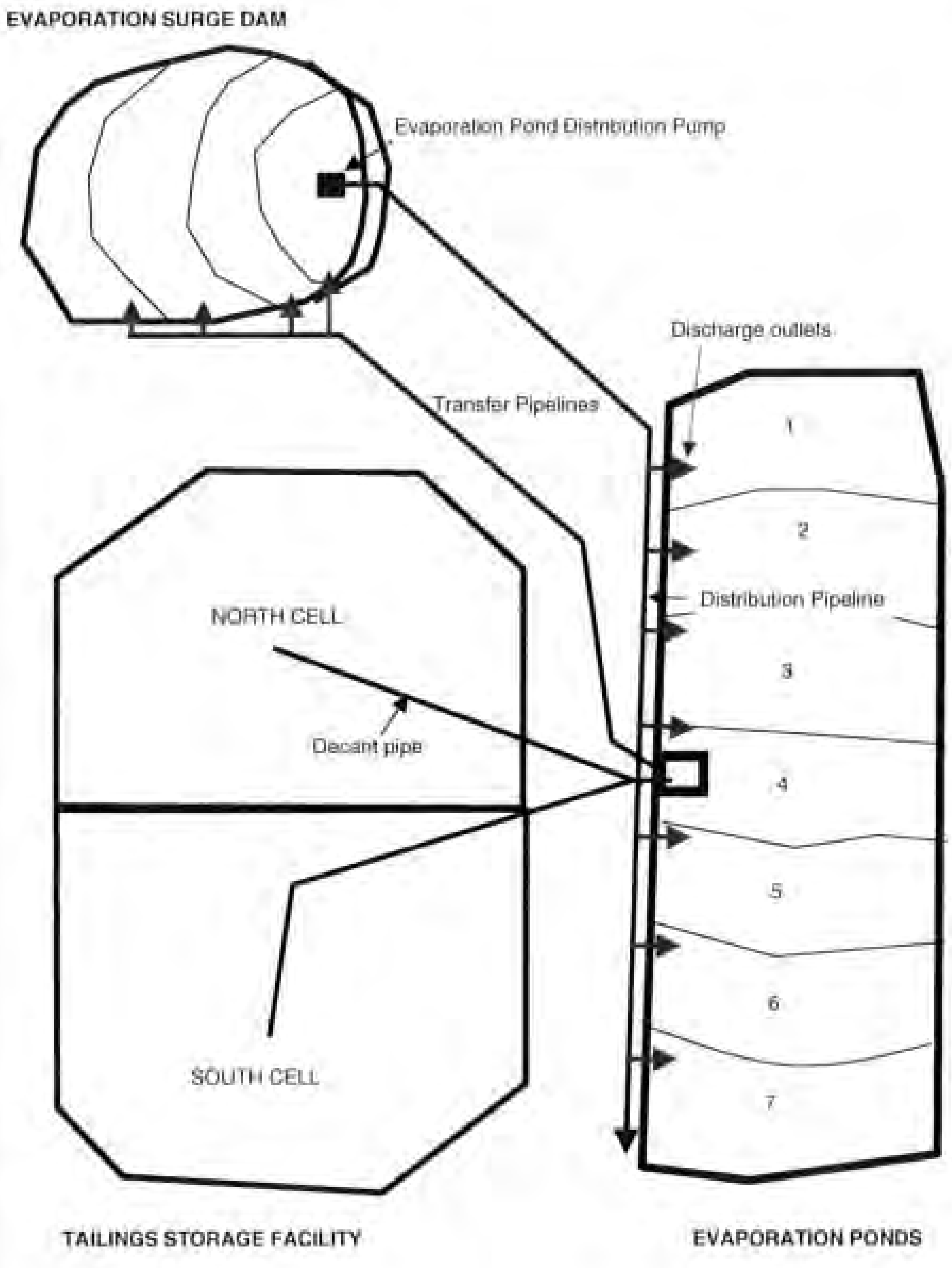
BRM-98-01-WM_011A



Golder Associates		CLIENT	BLACK RANGE			PROJECT	SYERSTON NICKEL
		DRAWN	lb	DATE	02/14/00		Rehabilitation of
		CHECK	mjg	DATE	Feb-00		TSF Cell Outer Wall
		SCALE	nts		A4	PROJECT No.	99631001-F

Figure 12

BRM-98-01-WM_012A

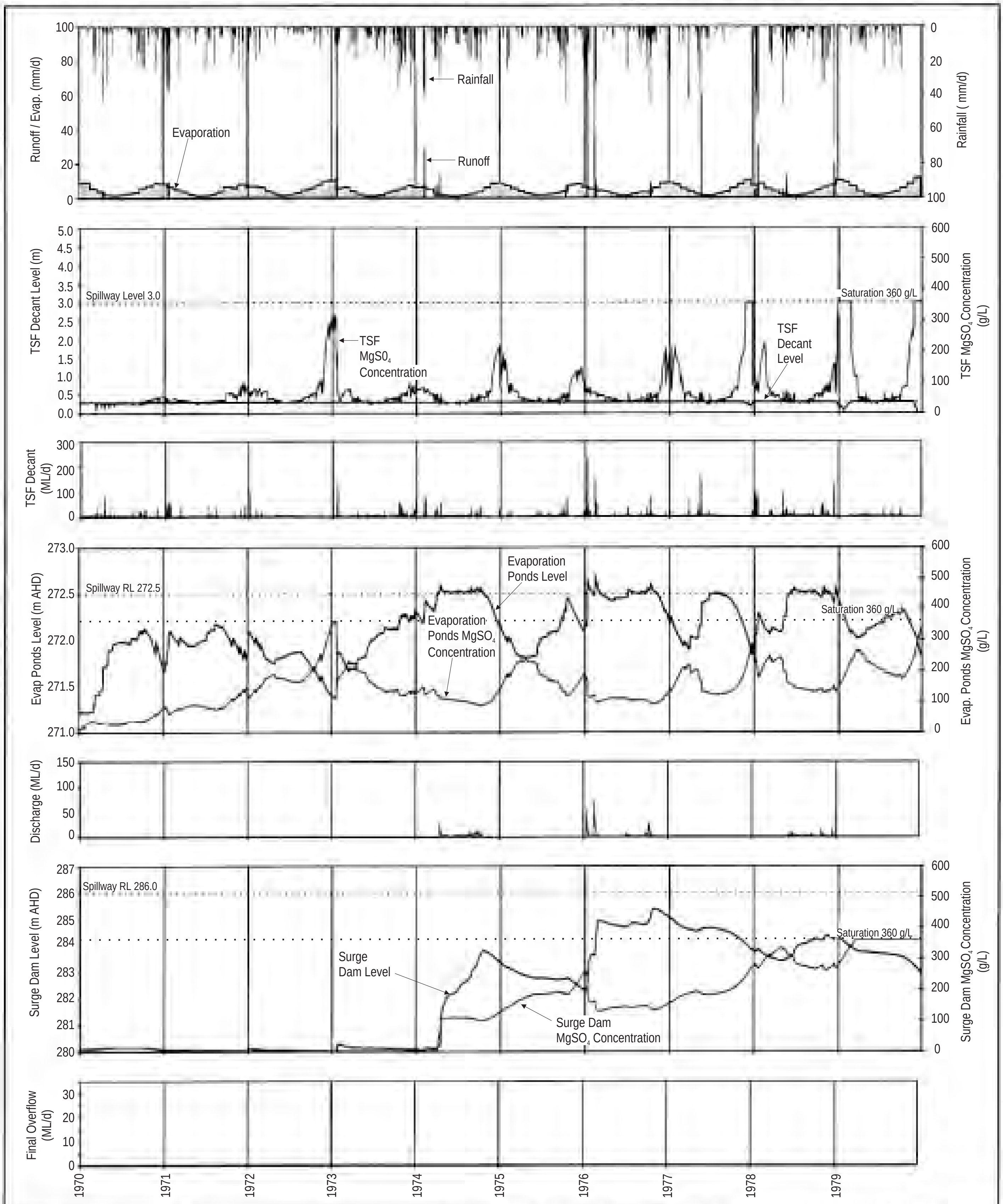


Golder Associates	CLIENT BLACK RANGE		PROJECT SYERSTON NICKEL	
	DRAWN lb	DATE 02/14/00	Decant Water Distribution System	
	CHECK mjg	DATE Feb-00		
	SCALE A4		PROJECT No. 99631001-F	Figure 13

Syerston - Daily Balance:

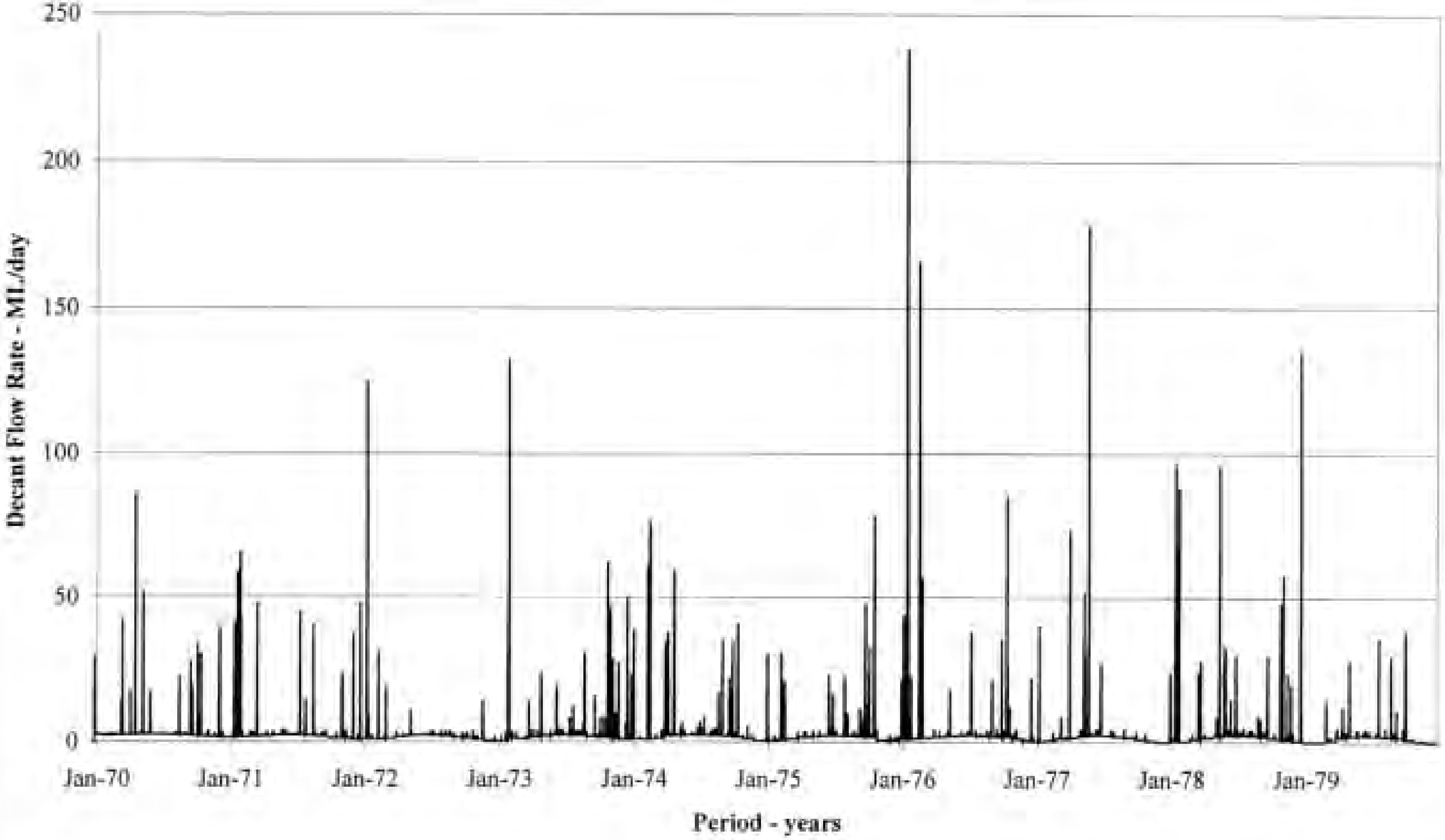
2.6 Mtpa, 48% solids, 1.1 t/m³, incl. heat effect, both TSF cells, 0.48 ML/d usage

99631001



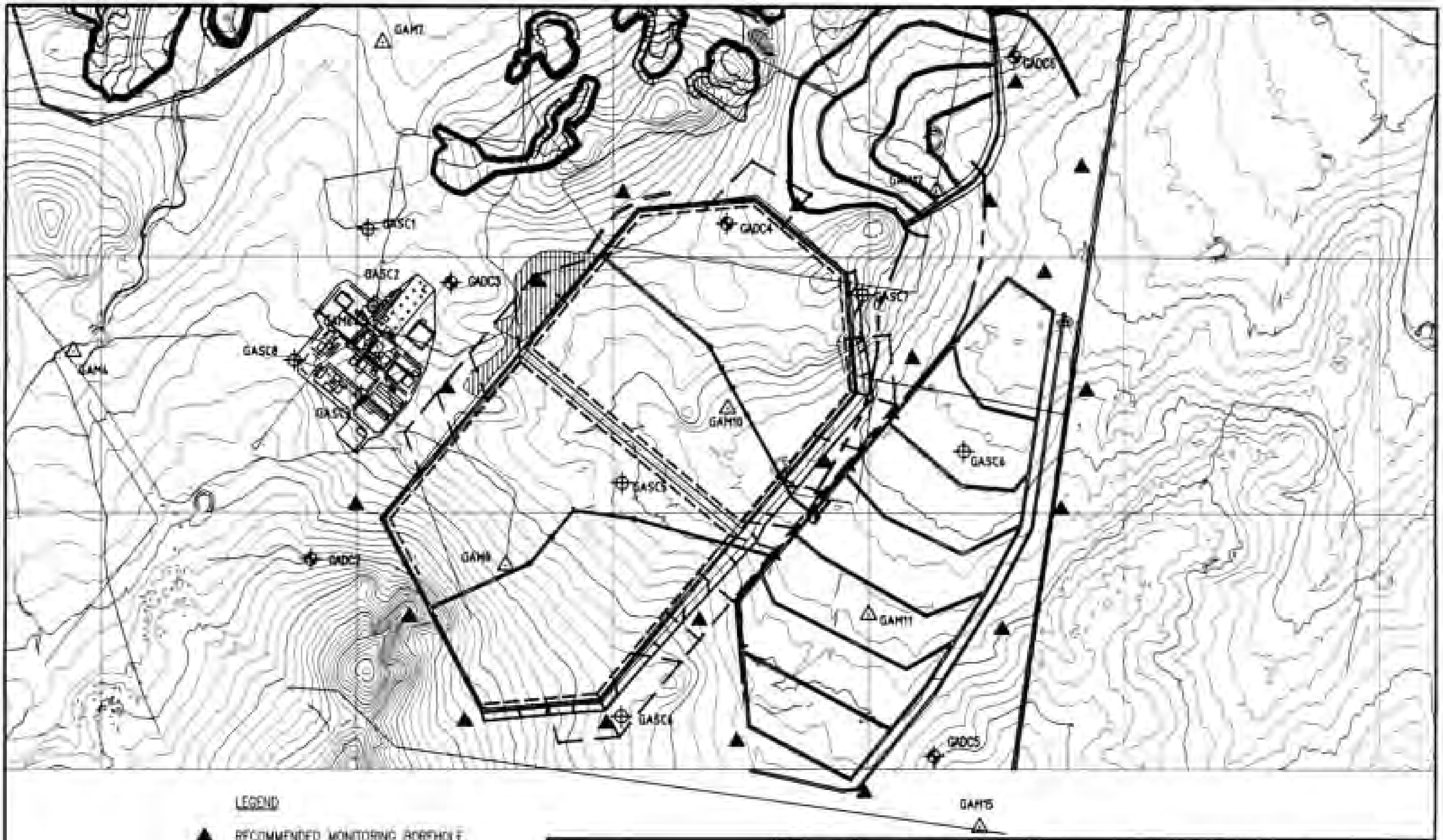
Golder Associates

CLIENT	BLACK RANGE MINERALS			PROJECT	SYERSTON NICKEL
DRAWN	gsf	DATE	3/13/00		TSF WaterBalance @ 48% RD
CHECK	mjg	DATE	Mar-00		Water Usage 0.48 ML/day
SCALE			A4	PROJECT No. 99631001-F	Figure 14



Golder Associates

CLIENT	BLACK RANGE	PROJECT	SYERSTON NICKEL
DRAWN gsf	DATE 03/21/00		TSF Water Balance
CHECK mjg	DATE Mar-00		Decant Transfer Rate
SCALE	A4	PROJECT No. 99631001-E	Figure 15



LEGEND

▲ RECOMMENDED MONITORING BOREHOLE

⊕ SHALLOW CORED BOREHOLE

◆ DEEP CORED BOREHOLE

△ MONITOR BOREHOLE

Golder Associates

BLACK RANGE MINERALS N.L.		SYERSTON NICKEL PROECT	
LMB	23-03-00	LOCATION OF RECOMMENDED MONITORING BORES	
DCB	24/3/00		
NOT TO SCALE	A4	99631001-F-39	Figure 16

BRM-98-01-WM_016A

APPENDIX E

SYERSTON NICKEL COBALT PROJECT

WATER SUPPLY BOREFIELD - HYDROGEOLOGICAL INVESTIGATION

PREPARED BY
COFFEY GEOSCIENCES PTY LTD

SEPTEMBER 2000
PROJECT NO. BRM-01\3.20
Document No. APPENDIX E-D.DOC

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1 INTRODUCTION

This Appendix is a summary of the report *Syerston Nickel Mine Water Supply Study* (September, 2000), prepared by Coffey Geosciences Pty Ltd (Coffey) for Black Range Minerals Ltd (BRM).

This Appendix presents the results of a hydrogeological assessment conducted on the unconsolidated alluvial sediments of the Lachlan River Valley, near Warroo in central New South Wales (NSW) (Figure E-1). The study area concentrated on the broad alluvial flats between Jemalong Gap and Bogandillon Gap and extended southwards to the southern sections of the Bland Creek System (Figure E-2).

Groundwater contained within the Lachlan River alluvial aquifers was identified as a potential source of raw water supply for the proposed Syerston Nickel Cobalt Project (Syerston Project), near Fifield, central NSW (Figure E-1). Two borefields, designated the “Western” and “Eastern” borefields - located 7 km apart, were hydrogeologically assessed (Figures E-1 and E-2).

The objective of the study was to assess the potential for the alluvial aquifers within the Lachlan Formation to supply the Syerston Project processing plant with raw water at a rate between 150 litres per second (L/s) (4,730 ML/year) and 300 L/s (9,460 ML/year) for a period up to 30 years.

The work conducted as part of this study included:

- development of test bores and piezometers in the Lachlan Formation;
- pumping tests and assessment of aquifer hydraulic parameters;
- chemical analysis of Lachlan and Cowra Formation groundwater and Lachlan River water; and
- modelling of the potential hydrogeological and hydrochemical effect of the proposed groundwater extractions on the Lachlan and Cowra Formations.

2 REGULATORY BACKGROUND

The proposed Western and Eastern borefields for the Syerston Project are located within the central southern section of the Department of Land and Water Conservation’s (DLWC’s) Zone 5 of Groundwater Management Area 11 (Figure E-3). As part of NSW’s State Groundwater Management Policy, an Upper Lachlan Groundwater Management Plan was developed in February 1997 by the DLWC with the objectives to:

- ensure ecological sustainability of the resource;
- allocate water equitably;
- encourage development which optimises economic benefit to the region, State and Nation while protecting the wider environment; and
- slow, halt or reverse any degradation in groundwater resources.

The Upper Lachlan alluvium has been classified as the fifth highest of nineteen high risk inland aquifers (DLWC, 1998).

Groundwater Management Area 11 is divided into 8 zones within the Lachlan River alluvium and its tributaries. Area 11 is located upstream of Lake Cargelligo and extends to the headwaters of the Lachlan River. The total amount of groundwater which could be abstracted from each zone was estimated by the DLWC from the average saturated thickness, an assumed drainable porosity and aquifer surface area. Refinements to the estimate are made when more accurate data becomes available.

Groundwater usage for Zones 5 and 6 is shown in Table E-1.

Table E-1
Groundwater Use in Zones 5 and 6 of
DLWC Groundwater Management Area 11

Zone	Area (ha)	Average Saturated Thickness (m)	Assumed Porosity %	Volume Available (ML/yr)	Allocation Ceiling (ML/yr)	Allocations as of 1999 (ML/yr)
5	207,181	92	0.12	251,601	125,801	18,537
6	94,127	92	0.15	142,885	71,443	16,704

Note: The available volume assumes 33% of available recharge and a 30 year allocation period.

Authority to grant licences for abstraction of groundwater rests with the DLWC under Part 5 of the NSW *Water Act, 1912*. Applications for production bore licences were made by BRM in July 1998.

3 DESCRIPTION OF THE EXISTING ENVIRONMENT

3.1 TOPOGRAPHY

The proposed Syerston Project water supply borefields are located on the extensive floodplain of the Lachlan River near Warroo and on the northern banks of the river, at a surface elevation of approximately RL +210 m AHD. The alluvial flat is restricted in width to the east and to the west by rock outcrops at Jemalong Gap and Bogandillon Gap respectively (Figure E-2). From the proposed borefields, the relatively flat floodplain extends some 40 km north towards the mine site and then rises into low hill terrain. The Syerston Project mine site is located approximately 65 km north-north-west of the proposed borefields. Basement rocks intermittently protrude through the alluvium and crop out as widely-spaced, steep-sided, rocky hills and ridges with a predominantly north-east/south-west strike.

3.2 GEOLOGY

The Lachlan River alluvium consists of Quaternary to Tertiary age fluvial clay, silt, sand and gravel sediments which are subdivided into the upper Cowra Formation and the underlying Lachlan Formation. Depth to basement bedrock is highly variable, ranging from 0 m to over 140 m beneath the surface. The deep incised Lachlan Palaeochannel is orientated east-west and joins the north-south trending Bland Creek Palaeochannel near the proposed borefields. A summary of the regional geology is included in Figure E-2.

The Lachlan Formation occupies the valley palaeochannel floor that is incised into the underlying basement. It is not exposed at the surface. The Cowra Formation overlies the Lachlan Formation, and overlaps onto the basement at the fringes of the palaeochannel. Cross-sections of the palaeochannels based on DLWC records and the recent study data are shown in Figures E-4, E-5 and E-6. Cross-section locations are given in Figure E-2.

Figure E-2 indicates the location of the regionally extensive Lachlan River and Bland Creek Palaeochannels in which the Lachlan Formation sediments have been deposited. The proposed borefields are located near the confluence of the Lachlan River and Bland Creek Palaeochannels in the deepest section of the Lachlan River Palaeovalley.

3.2.1 Cowra Formation

The Cowra Formation consists of interbedded clay and silt with minor sand and gravel lenses. The Cowra Formation sediments differ considerably from the Lachlan Formation in both colour and composition. The Cowra Formation is dominantly orange-brown to pale brown clay and silt with minor sand and polymictic gravel. The thickness of the Cowra Formation varies from 30 m to 40 m at Cowra, 64 m at Forbes and 80 m near Mulguthrie Mountain. Wood is generally absent in the Cowra Formation and no pyrite was noted in DLWC test bores (Williamson, 1986).

3.2.2 Lachlan Formation

The Lachlan Formation is restricted in width beneath the floodplain and consists of light grey, interbedded sand and gravel with minor silt and clay units. The subrounded to rounded sand and gravel are dominantly quartzose sediments, with lesser chert and jasper. The sand and gravel frequently occur in the deeper lithological sequence in bands from 10 m to 20 m thick. Disseminated pyrite occurs in deeper zones that may cement sediments or be present as concretions or replacements of wood. Wood fragments may also be present.

The depth of the Lachlan Formation gradually increases to the west. Depth to the base of the Lachlan Formation ranges from 75 m to 90 m near Jemalong Weir (Williamson, 1986) to 137 m in the Western borefield.

3.2.3 Basement Lithologies

Bedrock below the Lachlan River floodplain consists of Silurian phyllite, schist, micaceous siltstone, sandstone, dolomite, andesite and conglomerate within the north-south trending Tullamore and Murda Synclines. Outcropping bedrock consists of the Devonian Weddin Sandstone at Jemalong Gap. Andesite, dacite, rhyolite, tuff and limestone are present north of Goobang Creek whilst sandstone, shale and conglomerate are located at Mulguthrie Mountain along with the Womboyne Conglomerate at Bogandillon Gap. Valley-in-valley palaeochannels are present within the bedrock profile.

3.3 HYDROGEOLOGY

Groundwater movement is generally from east to west. Between Jemalong Gap and Bogandillon Gap, the major aquifer is the deep, confined sands and gravels of the Lachlan Formation. Few irrigation bores are located north of the Lachlan River between Mulguthrie Mountain and the Warroo channel system. The Bland Creek Palaeochannel, which also contains the Lachlan Formation, enters the Lachlan system to the south of Mulguthrie Mountain and east of the Bogandillon Range (Figure E-2).

3.3.1 Cowra Formation

The Cowra Formation comprises numerous clayey sand and gravel aquifers separated by thick silty clay beds. Cowra Formation aquifers are generally extensive, however the potential for groundwater supplies is limited compared with the Lachlan Formation as there is less water level drawdown available and the aquifer is generally less permeable. Groundwater yield from the Cowra Formation is generally less than 60 L/s.

Within the Cowra Formation, the natural northerly shallow groundwater movement in the Bland Creek Palaeochannel has been reversed in recent times and the Bland Creek catchment is thought to no longer contribute underflow to the Lachlan River system (Coffey, 1994a). This is primarily due to the development of the Warroo Groundwater Mound within the Jemalong-Wyldes Plains Groundwater Management Area (JWPGMA). The mound results from vertical infiltration of surface water from leaking earthen irrigation channels and increased groundwater accessions due to the changed landuse for grazing and irrigation (Anderson *et al*., 1993).

Soil salinisation and water logging is a recognised problem in the Jemalong-Wyldes Plains area, south of the Lachlan River, especially near Bogandillon Range.

3.3.2 Lachlan Formation

The Lachlan Formation is restricted to the entrenched bedrock section of the Lachlan River Valley and contains the more productive aquifers. The sand and gravel confined aquifers are irregularly distributed, hydraulically interconnected and vary considerably in thickness. Maximum aquifer thickness does not necessarily correspond with the deepest part of the valley, nor in the area of the most productive aquifers. The Lachlan Formation aquifers vary in the silt and clay content and therefore not all aquifers are potential groundwater extraction targets.

Based on available information, the Lachlan Formation aquifers between Jemalong Gap and Bogandillon Gap are generally extensive, although the palaeochannel constricts to a few kilometres in width at each Gap.

In the Jemalong Gap to Bogandillon Gap area, licensed bore data indicate groundwater yields from the Lachlan Formation of up to 195 L/s. To the east of Forbes, production bores extract groundwater for Parkes town and Northparkes Copper/Gold Mine water supply. Groundwater yields up to 200 L/s are obtained in the Parkes area from combined production bores screened in both Lachlan and Cowra Formation aquifers.

Transmissivities in the Lachlan Formation range from 23 m^2/d to 3,374 m^2/d (Williamson, 1986). Standing water levels are between 2 m and 10 m beneath the surface and major aquifers are potentially intersected between 80 m and 120 m beneath the surface (Williamson, 1986).

Outside the palaeochannel it is unlikely that large groundwater yields (in excess of 60 L/s) would be available as bedrock is encountered at a depth less than 80 m beneath the surface and the Lachlan Formation is not usually present or thins out markedly at or below this depth.

Within the Bland Creek Palaeochannel, groundwater yields from the Lachlan Formation range up to 50 L/s. Transmissivity values range from 94 m^2/day to 555 m^2/day (Coffey, 1994a).

The Warroo Groundwater Mound appears to have applied a hydraulic pressure loading to the Lachlan Formation within the Bland Creek Palaeochannel and caused a reversal of groundwater flow away from the Lachlan system toward Lake Cowal (Coffey, 1994b).

3.3.3 Groundwater Quality

Salinity varies substantially in the Lachlan River Valley from less than 500 mg/L to in excess of 30,000 mg/L. Salinity tends to increase away from rivers, creeks and channels towards basement rock outcrops. There is a natural increase in salinity downstream along the groundwater flow path from east to west.

In the study area, the total dissolved solids (TDS) of shallow aquifers in the Cowra Formation generally range from 800 mg/L to 1,000 mg/L. Groundwater in the Lachlan Formation is around 650 mg/L TDS at Mulguthrie Mountain and in excess of 1,950 mg/L TDS in the restricted bedrock channel near Condobolin (Williamson, 1986).

The Lachlan Formation has sodium in excess of magnesium and calcium, though occasionally the latter two ions are in reverse order. Of the anions, bicarbonate exceeds chloride and sulphate is subordinate (Williamson, 1986).

The Lachlan Formation groundwater in the Bland Creek Palaeochannel (Hawkes, 1998) is described as Na:Cl dominated with lower bicarbonate than the overlying Cowra Formation waters. In general, the salinity of the Bland Creek Palaeochannel groundwater is suitable for most irrigation purposes.

3.4 GROUNDWATER USERS

This section presents a summary of other registered groundwater users in the vicinity of the proposed Syerston Project Western and Eastern borefields. The information presented in this section is based on DLWC records available at the time of preparation of Coffey (2000).

Data on registered groundwater bores obtained from DLWC records is presented in Coffey (2000). Where DLWC data is insufficient to clearly define between the Lachlan and Cowra Formation, it was assumed that bores screened at depths greater than 100 m intersected the Lachlan Formation; or where grey sand, clay or wood and pyrite are noted in the geological log. It was assumed that shallow bores without the relevant characteristics are screened in the Cowra Foundation. It is noted that in some cases the Lachlan/Cowra Formation interface can extend to approximately 80 m below surface.

3.4.1 General Description of Parkes/Forbes Groundwater Use

The Parkes, Northparkes Mine and Forbes borefields, to the east of Jemalong Gap, are the closest example of monitored, large scale groundwater users within the Lachlan Formation.

Comparisons between the Forbes/Parkes and the BRM borefield needs care, however, as the DLWC indicate the Lachlan River varies from being a gaining or losing stream at various locations along its length, with groundwater mounding against bedrock restrictions to the east of Jemalong Gap and along the foothill of the Bogandillon Range.

At the Forbes/Parkes borefields it is apparent that:

- Forbes town water supply at Red Bend relies mainly on river water, with only limited groundwater extraction;
- the Parkes/Northparkes borefield extracts groundwater of a rate of 2,000 ML/year (65 L/s) to 4,000 ML/year (131 L/s), with up to 5,000 ML/year (165 L/s) in droughts. Significant water level drawdowns of 10 m about 1.2 km away and 15 m approximately 2 km away from the wellfield were measured in 1996/97 (CM Jewell & Associates, 1998); and
- computer modelling (CM Jewell & Associates, 1999) indicates the safe yield for the Parkes/ Northparkes borefield is approximately 1,200 ML/year to 1,600 ML/year, with an upper potential limit of 1,800-2,000 ML/year. Care should be taken when comparing Parkes to the Syerston borefields as there is significant interference between the Parkes bores (<500 m separation at 40-50 L/s extraction rates). The Parkes bores are also located close to the northern limit of the Lachlan alluvials, which means that boundary conditions may occur earlier than at the Syerston borefield.

3.4.2 Syerston Borefield Extraction in Zones 5 and 6 of GWMA11

The proposed BRM borefields are within the DLWC Upper Lachlan Groundwater Management Area 11, on the central southern section of Zone 5, which has the Lachlan River as its southern boundary (Figure E-3). Groundwater extraction by BRM in Zone 5 would potentially affect Zone 6, to the south of the Lachlan River that contains the JWPGMA. The JWPGMA has been studied by Coffey and others during the 1990s as it has soil salinisation and water logging problems due to elevated groundwater levels from excess irrigation and leaking canals. Based on modelling studies (Coffey, 2000) extraction for the Syerston borefield can assist in this water logging amelioration.

Total available groundwater allocations in Zones 5 and 6 are listed in the Area 11 Groundwater Management Plan for the years 1997-2002 at 125,801 ML/year and 71,443 ML/year respectively. Current allocations as of December 1999 are 18,537 ML/year and 16,704 ML/year respectively. The Zone 5 allocation does not include BRM's groundwater requirement. The inclusion of BRM requirements with the current allocations represents 20% to 25% of total current allocation for Zones 5 and 6, rather than of the total available allocations.

3.4.3 Cowra Formation

Seventy-seven percent of the domestic and stock bores within the Cowra Formation aquifer are less than 50 m deep. Bores less than 50 m deep from DLWC data are shown on Figure E-7 and are interpreted to be in the Cowra Formation. The DLWC data indicates that there are 93 stock and domestic "Cowra Formation" bores within a 10 km radius of the proposed Western and Eastern borefields.

Based on DLWC data, there are 29 registered irrigation bores extracting groundwater from the Cowra Formation (Figure E-8). All these bores are privately owned. Groundwater yields for irrigation purposes range from 5 L/s to 63 L/s. Three registered irrigation bores are within a 10 km radius of the proposed borefields including GW027275, GW029336 and GW029373 (Figure E-8). Details of these bores are summarised in Table E-2.

Table E-2
Cowra Formation Registered Irrigation Bores
within 10 km Radius

Work No	Date Completed	Completed Depth (m)	Yield (L/s)
GW027275	1/06/67	42.7	23
GW029336	not recorded	18.3	9
GW029373	1/08/68	46	15

3.4.4 Lachlan Formation

Based on an assessment of borehole depth and geology from DLWC records, 32 registered bores, not including DLWC monitoring bores, intersect the Lachlan Formation in the study area (Figure E-9). A summary of bore details and purpose is presented in Coffey (2000). Ten bores are indicated as being used for irrigation purposes. Three registered irrigation bores are within a 10 km radius of the proposed production borefields including GW700423, GW053852 and GW62081 (Figure E-9). Details of these bores are summarised in Table E-3. Each of these bores is privately owned.

Table E-3
Lachlan Formation Registered Irrigation Bores
within 10 km Radius

Work No	Date Completed	Completed Depth (m)	Yield (L/s)
GW053852	1/04/83	138.7	Not recorded
GW062081	1/01/83	128	59.9
GW700423	19/06/97	135	Not recorded

3.4.5 Groundwater Yield in Borefield Areas

Groundwater yields for the Lachlan Formation in the vicinity of the borefields range from less than 1 L/s up to 200 L/s (Coffey, 2000). The lower limit in groundwater yield from the Lachlan Formation is typically due to poor bore construction and/or pump maintenance. Groundwater yields from the Cowra Formation aquifer range from 1 L/s to 60 L/s.

Most irrigation bores occur west of the proposed borefields. Relatively few bores are present within the Jemalong Wyldes Plains Irrigation Area, due to readily accessible surface water in this area.

Irrigation bores are located at the intersection with the Bland Creek Palaeochannel and to the south along the palaeochannel. The southern bores are associated with the proposed Cowal Gold Mine water supply. Additional irrigation bores are located to the west near Erronwallong Mountain.

Yield information in available records is poor although significant yields are recorded both east (GW039316 with 196 L/s) and west (GW057859 with 100 L/s) of the proposed borefields (Figure E-9).

3.5 GROUNDWATER LEVELS

Water levels in the aquifer of the Lachlan River and Bland Creek Valleys have been measured in DLWC observation piezometers for over thirty years. Groundwater levels in the Lachlan River Valley between Jemalong Gap and Condobolin and in the Bland Creek Valley to the south range from 0.3 m to 69.5 m below surface. Figure E-9 shows the locations of the DLWC piezometers and Figure E-10 indicates long term piezometric surface fluctuations for DLWC piezometer GW36087, which is the closest monitoring piezometer to the western Syerston borefield. The piezometric surface has a 3.5 m variation since 1976 in the Lachlan Formation, and nearly 4 m in the Cowra Formation. Additional hydrographs within the study area to the east, west and south are presented in Coffey (2000).

Groundwater level variations are correlated to rainfall, with “wet” years such as 1983 and 1988/89 resulting in major aquifer recharge events compared to “dry” years. A similar pattern is recorded for other bores where data is available.

The piezometric surfaces in the Lachlan Formation and the contact with the Cowra Formation (GW 36087/3 and GW 36087/2, respectively) are responsive to regional recharge events (with time lag) and are hydraulically interconnected. These piezometric surfaces are variable, and generally up to 2 m higher than in the shallower Cowra Formation (GW36082/1) indicating a greater pressure head in the Lachlan Formation. The piezometric surface in the Cowra Formation is more responsive to recharge events, the response being more rapid than deeper Lachlan Formation aquifer units. These facts suggest that hydraulic connection between the Lachlan and upper Cowra Formation aquifer is not significant and there is no significant recharge from shallow to deeper aquifers at this location, under the current steady state condition.

Water levels monitored near the proposed Syerston Project borefields in Zone 5, indicate a 2 m to 3 m net rise in water level in the Cowra Formation between 1968 and 1993 with changes in the piezometric surface generally related to seasonal events. Zone 6, which includes the JWPMA, had a dramatic rise in water level in the 1950s due to flooding, with rises of up to 5 m and no apparent recession. The groundwater mound was centred beneath a shallow prior stream alluvial deposit and was noted to be still expanding (Bish & Williams, 1994). Between 1988 and 1992 the mound rose by approximately 1 m within the Cowra Formation. The area at the crest of the mound is at risk from water logging and salinisation, whilst groundwater within the mound drains toward Bogandillon Creek and Lake Cowal (Bish & Williams, 1994).

3.6 REGIONAL HYDROLOGY

The Lachlan River Valley has a catchment area of about 84,700 km^2. The mean annual flow of the river at Forbes is about 1.27x10^6 ML with 60% of the flow occurring between June and September. Operation of Wyangala Dam, Lake Brewster and Lake Cargelligo has had substantial effects on the river flow, with changed seasonal patterns, reduced flow variability and lower water volumes in the downstream reaches of the river (Bish & Williams, 1994).

Water level in the Lachlan River is gauged at Jemalong Gap and is generally at approximately RL +220 m AHD, although may rise to RL +225 m AHD during periods of high flow. Significant floods reportedly occur about once every ten years although local flooding in the vicinity of the river may occur more frequently. Flood runoff from the Lachlan River flows into the floodplain from breakouts at various points along the river. Significant flows occur to the south-west into Lake Cowal.

Flooding depths to the north of the river have been observed to be less than 1 m at the proposed Western and Eastern borefields. The Western borefield lies on the southern boundary of a floodway.

3.7 LANDUSE AND OWNERSHIP

Landuse in the proposed borefield area is dominated by sheep and cattle grazing on both native and improved pastures. Some cropping of wheat and barley is also practiced. The reserve area along the Lachlan River is used for recreational purposes including camping and fishing. Details of landowners in the vicinity of the Western and Eastern borefields are summarised in Table E-4, with the landholdings indicated on Figure E-11.

Table E-4
Land Owners in the Vicinity of the Eastern and Western Borefields

Number on Figure E-11	Landholder
1	H & M Smart
2	Crown Land
3	K Simmonds
4	T & I Simmonds
5	W Patterson
6	Mulguthrie Pastoral Co
7	F Hayes
8	A & M Ridley
9	I & K Brockmann
10	J Peters

4 FIELD INVESTIGATIONS

4.1 EXTRACTION AND MONITORING BORE DETAILS

Table E-5 summarises completion bore details at the Eastern and Western borefields and the monitoring piezometers used in the study. Graphical logs of the bore geology and construction details are presented in Coffey (2000). Bore locations are given in Figures E-12 to E-15. Bores developed specifically for this investigation include:

- monitoring piezometer MW-W1, and test production wells PB-W1 and PB-W2, in the Western borefield; and
- monitoring piezometer MW-E1 and test production well PB-E1 in the Eastern borefield.

Table E-5
Monitoring Well and Piezometer Construction Details

Bore ID	Date Completed	Total Depth (m)	Aquifer Zone (m)	Slotted Interval(s) (m)	Estimated Depth to Lachlan Formation (m)
PB-W1	31/3/99	141	108-137	126-136	108
MW-W1	26/7/99	137	103-136	126-136	100
PB-E1	23/8/99	128	107-126	108-110 115-119 121.5-125.5	97
MW-E1	23/8/99	127	104-126	108-126	97
PB-W2	17/11/99	137	114-135	114.5-116 125-133 134-135	109
36087/1	1/09/75	42.6	35.1-38.1	30.4-36.5	-
36087/2	1/09/75	93.8	80.8-91.4	81.6-87.7	-
36087/3	1/09/75	134.1	119-136	121.9-128	85
36089/1	1/07/75	59.4	48.7-51.8	50.2-53.1	-
36089/2	1/07/75	94.4	77.7-88.3	85.3-88.3	-
62081[1]	15/10/83	128	91-101.5	-	-

[1] This borehole was logged by Coffey (Report H119/3-AA, 1983) but no screens were installed at the time of the report.

Drilling was carried out under authority of the DLWC Test Bore Licence 70BL227110. The test/production bores were completed by installing stainless steel, wire-wound screens in the Lachlan Formation aquifer zone and mild steel casing to surface. Monitoring piezometers were completed with 100 mm diameter PVC piezometers. The annulus outside the screened/slotted horizons of all holes was filled with rounded gravel, sealed with bentonite and then backfilled to surface using drilling spoil.

4.2 FIELD TESTING

Test pumping of PB-W2 and PB-E1 was conducted during September and November 1999, respectively. A step drawdown test was conducted on PB-W1, however, it was found to be unsuitable for a constant discharge test and was reclassified as a monitoring piezometer.

4.2.1 Western Borefield

PB-W1 had a step drawdown test conducted at yields of 13 L/s, 19 L/s, 28 L/s, 33 L/s and 38 L/s. A step test on PB-W2 was run at groundwater yields of 35 L/s, 55 L/s and 73 L/s. Recovery after the steps was measured for 1.5 hours.

Drawdown of water levels during the constant discharge test was monitored in:

- MW-W1, 17 m north of PB-W2;
- PW-W1, 15 m east of PB-W2;
- DLWC monitoring piezometer nest GW36087, 80 m south/south-west;
- PB-E1, approximately 7 km south-east;
- DLWC monitoring piezometer nest GW36089 approximately 2.6 km south.

Plots of step tests conducted on PB-W1 and PB-W2 are presented in Coffey (2000). A 3-day constant discharge test at 72.8 L/s on PB-W2 was conducted after the step test recovery. Results are also presented in Coffey (2000).

On completion of pumping, water level recoveries were measured in the pumped bore and monitoring piezometers for approximately 39.5 hours (2,370 minutes). The transmissivities derived from the PB-W2 pump-out test indicate values from 610 m^2/day to 1,050 m^2/day in the proposed Western borefield region and storativity ranges from 1 x 10^{-4} to 8 x 10^{-3}. These values indicate there is a good potential for groundwater supply from the Western borefield.

Delayed leakage into the Lachlan Formation was noted from the lower section of the Cowra Formation, but none in the shallow sections of the Cowra Formation.

The groundwater level at the start of the test was 4.11 m, with 95% recovery after 2,370 minutes (39.5 hours) (54% of pumping time). This indicates the aquifer was not overly stressed during the three day test.

4.2.2 Eastern Borefield

A step drawdown test was conducted in PB-E1 at yields of 22 L/s, 44 L/s and 84 L/s. After allowing the water level to recover overnight, a 72-hour constant discharge test was run at 84 L/s.

Drawdown of water levels during the test was monitored in several bores:

- MW-E1, 26.8 m north of PB-E1;
- MW-W1, about 7 km north-west;
- Stock watering well on the property “Serenity”, 1.3 km to the north;
- Irrigation bore GW062081 on the property “Narreman”, 2 km south across the Lachlan River; and
- DLWC monitoring piezometers GW36087/1, 2 and 3 approximately 7 km to the north-west.

Recovery of water level was observed for 24 hours after pumping. The results of the step tests conducted on PB-E1 on 3 September 1999 are summarised in Table E-6.

Table E-6
Summary of PB-E1 Step Test Results

Step	Yield (L/s)	Water Level at End of Step (mbgl)[1]	Drawdown at End of Step (m)	Estimated Transmissivity (m^2/day)
1	22	5.88	1.24	1400
2	44	8.13	3.49	1400
3	84	13.68	9.04	1800

[1] Metres below ground level

Water level recovery was monitored at 4.63 m below ground, at 930 minutes after Step 3. The constant groundwater discharge test on PB-E1 averaged 83.5 L/s over 72 hours. Aquifer hydraulic interpretation is given on Table E-7.

Table E-7
Summary of PB-E1 Constant Discharge Test Results

Time Since Start of Test (minutes)	Water Level (mbgl)[1]	Drawdown (m)	Yield (L/s)	Estimated Transmissivity (m^2/day)
0	4.63	0	-	-

1440 (24 hours)	14.96	9.94	83.8	1800
2880 (48 hours)	15.34	10.32	83.6	1100
4320 (72 hours)	15.62	10.60	83.2	980

[1] Metres below ground level

On completion of pumping, water level recovery was measured for 1558 minutes (25.8 hours) in the pumped bore. Estimated transmissivity and storativity values are summarised in Table E-8 for the installed monitoring wells MW-E1 and MW-W1. All other monitored bores either did not recover during the monitoring period or recovered to a level higher than the pre-test water level. Detailed results are presented in Coffey (2000).

Table E-8
PB-E1 Constant Test Groundwater Levels

Well ID	Distance from PB-E1 (m)	Formation	Estimated Transmissivity (m^2/day)	Estimated Storativity
PB-E1	0	Lachlan	-	-
MW-E1	26.8	Lachlan	3,172	7.5 x 10^{-3}
MW-W1	7,000	Lachlan	610	8 x 10^{-3}

The water level in PB-E1 was 90% recovered in 35% of the pumping time, which indicates the aquifer was not stressed, and is areally extensive. The greater than 2 m drawdown recorded in MW-E1, 26.8 m away from the pumping well is a small amplitude for the high discharge rate and distance. This indicates a highly permeable aquifer system.

4.2.3 Water Quality

4.2.3.1 Groundwater

Laboratory analysis of samples collected from PB-E1 and PB-W2, and field measurements, are presented in Coffey (2000). No parameters exceed the 1992 ANZECC Freshwater Ecosystem or Drinking Water Quality except for ammonium in PB-E1 and total phosphorous in PB-W1, PB-W2 and 36087/1.

The Syerston Project process plant water quality requirement for ore processing is for low salinity water. In general the groundwater salinity from the proposed Black Range Minerals bores in the Lachlan Formation aquifer varies from 760 mg/L to 870 mg/L (low salinity). The pH is slightly alkaline and nutrient levels (ammonium and total phosphorous) are elevated. All metals are at low concentrations and are within ANZECC (1992) criteria.

The bores PB-E1, PB-W2, 36087/2 and 36087/3 all have Na/Cl/HCO_3 dominant groundwater. Groundwater in the shallow Cowra Formation (36087/1) is HCO_3/Na/Mg dominant.

4.2.3.2 Surface Water

One sample from the Lachlan River was collected in November 1999. Analytical results are presented in Coffey (2000). The surface water is marginally more alkaline than the groundwaters and has a similar salinity to the shallower Cowra Formation aquifer. The metals are generally low, although the iron is marginally elevated. The sample was HCO_3/Mg/Cl dominant.

4.3 CONCEPTUAL HYDROGEOLOGY OF THE LACHLAN FORMATION

Based on a review of information and the results of the field programme, a conceptual model of the Lachlan Formation alluvial aquifer was developed for the study area. The coarse sand and fine gravels of the deeper Lachlan Formation comprise a preferential target for groundwater occurrence compared to the finer sands and clays of the shallower Cowra Formation.

4.3.1 Recharge

The Lachlan Formation gravels are potentially confined beneath the Cowra Formation clays and sands. Recharge to the Lachlan Formation and the lower portion of the Cowra Formation is indirect. This is due to laterally extensive clay layers forcing groundwater to follow long flowpaths in order to relieve pressure imbalances. The Cowra Formation comprises a number of confined aquifers that are linked more directly in the lateral rather than vertical direction.

Based on monitoring piezometer hydrographs (presented in Coffey, 2000), it is apparent that all aquifers respond to rainfall, with the Cowra Formation having a greater response than the Lachlan Formation. The degree of potential hydraulic interconnection between the Formations depends on the presence of low permeability layers (clays).

Test pumping results indicate the Lachlan Formation is recharged by the lower portion of the overlying Cowra Formation. Vertical flowpaths through the Cowra Formation that could potentially recharge the Lachlan Formation may be impeded by clay layers. The degree of connectivity between the two aquifers, however, can only be qualitatively assessed due to the heterogeneous nature of the geology and the information available from a limited number of boreholes.

No response to the western pump-out test was noted in the shallow Cowra Formation piezometer GW36087/1 (Figure E-12). Test results suggest that although flow is relatively easily induced between the Cowra Formation and Lachlan Formation, the rate of flow is delayed, possibly due to the presence of intervening clay layers (Coffey, 2000).

4.3.2 Groundwater Flow

Groundwater flow within the Lachlan Formation aquifers is generally constrained within the Lachlan River and Bland Creek Palaeochannels, ie. westward, sub-parallel to flow in the Lachlan River and northward, sub parallel to Bland Creek up to the confluence of the two systems. Groundwater flows toward Condobolin, from west of the confluence of the two systems. Local variations in hydraulic gradient and flow direction would be expected around bedrock highs projecting through the alluvial sequence.

4.3.3 Hydraulic Parameters

The underlying basement lithology is not impermeable, however the contrast between hydraulic conductivity in the Lachlan Formation and the basement would be so large that the basal contact is regarded as a no-flow boundary.

Test pumping results indicate that the transmissivity of the Lachlan Formation aquifers ranges from 500 m^2/day to 700 m^2/day in the Western borefield to 1,100 m^2/day to 1,500 m^2/day in the Eastern borefield. The variation potentially arises from changes in gravel thickness and sediment grain size.

At both test sites, no preferred directions in transmissivity were noted from observation piezometers and the aquifer may be regarded as isotropic. Storativity values range from approximately 10^{-3} in the Eastern borefield to 10^{-4} in the Western borefield, which are within the expected range for the aquifer system.

5 PHYSICAL AND CHEMICAL MODELLING

5.1 MODEL DESCRIPTION

Two numerical groundwater models were constructed to simulate groundwater flow behaviour in the vicinity of the proposed borefields and the surrounding aquifer. The specific aims were to:

- identify regional drawdown effects from groundwater extraction from the proposed borefields for up to 30 years; and
- identify potential impacts of groundwater extraction on other groundwater users in the area.

Model 1 was developed using the “Drain” package of MODFLOW, where the Lachlan River does not recharge the aquifer. As a result of consultation with the DLWC, Model 2 was set up using the “River” package of MODFLOW, whereby the Lachlan River is able to recharge the underlying aquifers, as well as incorporating a greater assessment of flood recharge to the aquifers.

Model inputs and outputs are described in detail in Coffey (2000). A summary description of Models 1 and 2 and their outcomes is provided below.

Based on available data at the proposed Syerston borefield, as well as extrapolated observations from operation of the Parkes borefield, it is estimated that the actual site conditions (ie. hydrogeological regime) is between the two modelled scenarios. Additional hydrogeological, aquifer and river response data would be accumulated during the initial phases of the borefield development allowing a better representation of site specific conditions by computer modelling.

The United States Geological Survey’s (USGS) MODFLOW (McDonald & Harbaugh, 1988) model was used to simulate the proposed groundwater extractions. MODFLOW is a cell-centred, finite difference model and is the industry standard modelling package for groundwater flow (Coffey, 2000).

The lateral extent of both the model domains was limited to a distance of 20 km upstream and downstream of the proposed borefields along the Lachlan River and 20 km to the south to incorporate the downstream section of the Bland Creek alluvium (Figure E-2). The extent of the models was estimated from analytical modelling, which found the extent of lateral drawdown to be approximately 20 km in response to continuous groundwater extraction over a period of 30 years.

The Jemalong Gap and Bogandillon Gap (Figure E-2) define the eastern and western extents of the model domains, where boundary conditions assessed from the available data could be applied within the models. The models used two layers to represent the local groundwater system – the upper layer representing the Cowra Formation, and the lower layer, the Lachlan Formation. Coffey (2000) provides information on model layering, surface elevations, Lachlan Formation/Cowra Formation interface elevations, and adopted hydraulic properties and hydraulic boundaries.

5.1.1 Hydraulic Properties

Model 1

Initial estimates of the hydraulic properties for each layer were estimated from the field programme, typical regional values, experience with similar investigations and from discussions with representatives from the DLWC. The values of the parameters were then refined during the calibration process. Table E-9 summarises the final parameters adopted for Model 1.

Table E-9
Model 1 - Summary of Hydraulic Parameters

Formation	Parameter	Value
Cowra	Horizontal Hydraulic Conductivity (K_h) Specific yield (S_y)	2-0.5 m/d 0.2
Lachlan/Cowra	Leakage (VCONT)	0.01-0.1 m/d/m
Lachlan	Transmissivity (T) Storage Coefficient (S_c)	200-2000 m^2/d 0.0001

Coffey (2000) presents figures showing the spatial distributions of the hydraulic conductivity of the Cowra Formation, vertical leakage between the Cowra and the Lachlan Formations and transmissivity in the Lachlan Formation. Storage coefficients and specific yield parameters were assumed to be uniformly distributed through the Lachlan and Cowra Formations respectively.

Leakage rates were based on typical values of vertical permeability of 1.0 x 10^{-1} m/d for silt to 1.0 x 10^{-6} m/d for clays that were observed within the JWPGMA (Coffey, 1994a). Based on this, vertical leakage was assumed to vary between 0.01 m/d/m and 0.1 m/d/m with the higher values occurring along the main channel of the Lachlan River.

The Lachlan River is modelled as a drain with conductivities varying between 100 and 500 m^2/d.

Model 2

Initial estimates of the hydraulic properties for each layer were estimated from the field programme, typical regional values, experience with similar investigations and from discussions with representatives from the DLWC. The values of the parameters were then refined during the calibration process. Coffey (2000) details the spatial distributions of the hydraulic conductivity of the Cowra Formation, vertical leakage between the Cowra and the Lachlan Formations, and transmissivity in the Lachlan. Storage coefficients and specific yield parameters were assumed to be uniformly distributed through the Lachlan and Cowra Formations respectively.

Pumping test data from fieldwork carried out in September 1999 and November 1999 were also used to estimate the initial leakage coefficients to be applied between model layers. The approach adopted for analysis of the pumping test data was the Boulton’s Delayed Yield, which was used to estimate the vertical permeability. Leakage between adjacent layers calculated from these estimates varied between 0.06 and 8 m/d/m. Table E-10 summarises the final parameters adopted for Model 2 following the completion of the calibration process.

Table E-10
Model 2 - Summary of Hydraulic Parameters

Formation	Parameter	Value
Cowra	Horizontal Hydraulic Conductivity (K_h) Specific yield (S_y)	7-30 m/d 0.02
Lachlan/Cowra	Leakage (VCONT)	0.002-8.0 m/d/m
Lachlan	Transmissivity (T) Storage Coefficient (S_c)	30-600 m^2/d 0.008

5.1.2 Recharge

Rainfall records were obtained from the Bureau of Meteorology for Bogan Gate, Condobolin, Forbes, Muddy Waters and Bedgerebong. The Bedgerebong gauge lays approximately 12km east of the Eastern borefield and provides the most representative estimate of rainfall behaviour in the study. A good correlation was found between Bedgerebong and the Muddy Waters station data to provide a complete record for purposes of generating a recharge record. Rainfall records from the above stations were also used for rainfall trace on the borehole hydrographs.

Recharge modelling was based on the composite (Bedgerebong and Muddy Waters) monthly rainfall record using the following exponential relationship:

$$\text{Recharge} = A(\text{Rainfall}-X)^B$$

where A, B and X are empirical constants, and recharge and rainfall are monthly averages expressed in mm/month and mm/day respectively.

The specific assessment of recharge is described for Models 1 and 2 in Coffey (2000) and summarised below.

Model 1

Monthly recharge was distributed by areal factors in the model according to zones determined from calibration trials. The major contributor to Lachlan Formation recharge was found to occur along and adjacent to the alignment of the river. Three distinct recharge zones were identified for modelling, two along the river and a third zone, with substantially lower recharge, applying over the remainder of the aquifer.

It was not possible to distinguish between the rainfall and river contributions to recharge. Table E-11 shows the average monthly recharge rates found to apply for the Lachlan Alluvials in the model calibrations.

Table E-11
Lachlan Alluvials - Average Monthly Recharge Rates

Month	Recharge (m^3/d)	Month	Recharge (m^3/d)
January	6,919	July	3,901
February	3,087	August	3,690
March	2,539	September	3,464
April	3,018	October	5,936
May	5,369	November	3,977
June	1,575	December	4,525

Model 2

Similar to Model 1, the recharge modelling approach adopted for Model 2 was based on the composite (Bedgerebong and Muddy Waters) monthly rainfall record using the exponential relationship described above.

Recharge was distributed in the first instance according to the topography and river alignment. A flood map was used to infer areas with depressed surface levels close to the river where recharge may be expected to occur at higher rates during and following flood events.

The recharge estimates were refined in a series of parameter estimation trials. For calibration trials conducted with the river simulation routine, A was found to vary between 0.001 and 0.0017, B between 1.65 and 1.90, and X between 0 and 0.4 mm/month (Coffey, 2000). For the final calibration trial the actual values adopted were: A = 0.001, B = 1.75 and X = 0.

5.1.3 Model Calibration

The models were calibrated for both steady state and transient conditions. The steady state calibration was based on groundwater data collected at DLWC monitoring sites for the period between September/October 1991. Groundwater levels during this period were not strongly influenced by excessive recharge or groundwater depletion. The results of the calibration of Model 1 for steady state conditions are shown on Figure E-16. The results of the calibration of Model 2 for steady state conditions are shown on Figure E-17. The residual heads shown in Figure E-17 represent the difference in the observed and modelled groundwater heads at each of the monitoring bore locations.

Time variant calibration was based on the simulation of groundwater flow conditions over the period January 1985 to June 1999. It was not possible to include river level variation in the time variant simulation due to the incompleteness of available data at gauging stations along the Lachlan River in the model area. However in the case of Model 2, the influence of the river was included as a seasonal variation in the model. This was achieved using average monthly river levels for the Mulgutherie station (412024) that were applied at each monthly stress period over the modelled simulation.

Figures E-18 and E-19 show the results of the time variant calibration of Model 1 (ie. comparison between simulated and observed groundwater levels). The calibration was assessed to be reasonable, based on the available data. A sensitivity analysis was also undertaken to examine the response of the model to variations in key aquifer parameters. The results of the sensitivity analysis are presented in Coffey (2000) and summarised below.

Figures E-20 and E-21 show the results of the time variant calibration of Model 2 (ie. comparison between simulated and observed groundwater levels). Model 2 does not display the detailed seasonal behaviour of the aquifer, however Figures E-20 and E21 demonstrate that the general long term trends in groundwater elevation predicted by the model are acceptable. To further investigate the time variant calibration of Model 2 and the response of the model to variations in key aquifer parameters, further sensitivity analysis was undertaken. The results of this analysis are presented in Coffey (2000).

5.1.4 Model Sensitivity Analysis

Model 1

A sensitivity analysis was undertaken to examine the Model 1 results over a range of possible parameter values.

The first set of sensitivity simulations examined the effect of the leakage rate (VCONT), which specifies the hydraulic connection between the Lachlan and Cowra formations. Model 1 leakage rates were in the range of 0.01 to 0.1 m/d/m (Coffey, 2000). Using these values the modelling found that there was only a marginal difference between the resulting drawdowns in the two aquifers. This may indicate that the model overestimated leakage rates. Three sets of sensitivity simulations were undertaken to examine the influence of reducing leakage rates by factors of 10, 100 and 1000. It was found that even when leakage rates were reduced by factors of 10 and 100 the simulated drawdowns in the two formations were essentially the same. It was only with the extreme reduction of leakage rates by a factor of 1000 that there was an appreciable difference between the simulated heads in the two formations. However, this difference in head was small compared to the simulated drawdowns, therefore, the sensitivity simulations suggest that the leakage rate between the two aquifers is not an important control on resulting drawdown.

The second set of sensitivity simulations examined the influence of hydraulic conductivity and transmissivity. Halving of aquifer conductivities indicated that decreases in conductivity result in a steeper cone of depression, so that the drawdown is higher near the two borefields but is approximately the same at the model boundaries.

Doubling the aquifer conductivities indicated a gradual steepening cone of depression. Drawdown near the borefields is lower but remains approximately unchanged in the vicinity of the model boundaries.

In summary, the sensitivity simulations undertaken for Model 1 show that the magnitude of the drawdown was largely insensitive to the aquifer parameters adopted in the model. This is attributed to the fact that the discharge rate of 200 L/s is much larger than the recharge rate and the aquifers do not reach a new equilibrium with the extraction rate. The heads within the aquifers are controlled predominantly by the aquifers water balance rather than its hydraulic properties.

Model 2

Sensitivity to River Conductance

A set of trials were carried out with a 50% reduction applied to the river conductances of the calibrated Model 2. This was directed at investigating the consequences of an overestimate in the calibrated river conductances, which, if incorrect, would lead to more favourable river recharge conditions being represented in the model than in the field. Such conditions would require less groundwater to be drawn from aquifer storage during the operational life of the two borefields.

The model was run with the 50% conductance for two cases:

- no pumping for a simulation period of 60 years; and
- the same river and recharge regimes as above, but with the proposed discharge of 200 L/s, distributed in six month intervals between the eastern and western borefields over 30 years, followed by a further 30 year recovery.

The model results from these two trials were used to determine the influence drawdowns. The same initial conditions were used, i.e. those for the baseline case with the final calibration parameters applied in the river simulation routine. This is conservative since it can be expected that if the conductance was lower by 50%, the groundwater heads would be correspondingly lower at the start of the trial for the 50% conductance case.

It is evident that the reduction of river conductance has a minor influence on the aquifer under pumped conditions, it is not sustained and groundwater conditions soon recover following extraction. The peak drawdown is marginally higher than for the baseline case but the recovery duration is the same, indicating that the conductance has a limited impact on the aquifer response.

Water budget output from Model 2 indicates that recharge from the river is greater under wellfield pumping conditions than under baseline conditions and that model recharge from the river is relatively insensitive to river bed conductance (permeability) after 30 years of pumping (Coffey, 2000).

Sensitivity to River Level

Sensitivity trials were carried out for three conditions under which the river levels applied at each monthly stress period varied: mean conditions and two other sets of low flow conditions referred to as the “Q_{50}” and “Q_{75}” conditions.

Mean conditions were determined as the river levels corresponding to average monthly flows at the Mulgutherie gauging station (412024) over the duration of the record that was monitored intermittently between 1915 and 1999. These levels were applied at each monthly stress period and repeated in annual cycles for the duration of the simulation.

Similar monthly levels were determined for the two low flow conditions using the following approach described for below the Q_{50} conditions:

- a probability analysis was carried out for monthly discharges using the Mulgutherie flow record;
- the flows which are exceeded for 50% of the time (Q_{50}) for a given month of the year were identified;
- the river levels corresponding to each of the monthly Q_{50} flows were determined from a rating curve.

There are clear limitations to this approach. However it was carried out because it was considered important to find a means of prescribing lower river levels on the Lachlan River, based on the available records for the purpose of a sensitivity analysis. It is recognised that any probability analysis of local river flow records is flawed without an accurate account of the effects of local irrigation and flood management. The absence of reliable data relating to human influence precludes such an analysis. Furthermore, the probability that monthly river flow would be sustained at Q_{50} levels for each month of the 60-year simulation period is likely to be significantly lower than 50% or indeed 75%. However, the approach has some use in reducing river levels while preserving their relative magnitude within the context of seasonal variation.

These were used to modify river depths applied in Model 2 for the following simulations:

- no pumping for a simulation period of 60 years; and
- the same river and recharge regimes as above, but with the proposed discharge of 200 L/s, distributed in six month intervals between the eastern and western borefields over a 30 years, followed by a further 30 year recovery.

Consistent with the previous sensitivity trial, the same initial conditions were used for each case. These trials indicated a detectable increase in peak drawdowns as river levels are reduced. For the eastern borefield there is an increase of 15 to 20% between the baseline and Q_{75} peak drawdowns (relative to final recovery level). For the western borefield this increase is 80 to 85%. The influence of river level on groundwater heads is pronounced and has an important bearing on model reliability (Coffey, 2000).

Sensitivity to Leakance

Model 1 trials indicated that the model was relatively insensitive to the leakance or leakage coefficient parameter (VCONT) applied in the model. VCONT specifies the hydraulic connection between the Lachlan and Cowra Formations. Despite the previous results, it was still considered necessary to investigate leakance with the river routine operational in Model 2.

Reduction of leakage rates by a factor of 25% gave a maximum difference between the simulated heads of 0.02 m over the entire trial period. This difference in head is small compared to the simulated drawdown; therefore, the sensitivity simulations suggest that the leakage rate between the two aquifers remains an unimportant control on resulting drawdown.

5.2 POTENTIAL GROUNDWATER DRAWDOWN EFFECTS

The results of both Model 1 (“worst case”) and Model 2 (“best case”) results indicate that groundwater abstraction at 200L/s is feasible.

Figures E-22 to E-25 present contour maps of simulated groundwater drawdowns at intervals of 1, 5, 10 and 30 years of extraction at 200 L/s for Model 1. Figures E-22 to E-25 show that over the 30-year period simulated by Model 1, no stabilisation of the areal extent of groundwater level drawdown was observed (ie. the modelled drawdown effect continued to grow) which suggests the rate of abstraction is exceeding the rate of recharge, with the effect being exacerbated by the limited extent of the Lachlan-Cowra aquifer system.

The drawdown after 30 years of pumping in Model 2 is shown in Figure E-26. Model 2 results indicate that the aquifer water levels recover quickly at the end of 30 years, as well as during the change from one borefield to another. Model 2 indicates the borefield will recover by over 90% within the first year after pumping stops, with full recovery within 10 years (Coffey, 2000).

The effect of groundwater level drawdown is transient. Once pumping is discontinued, ongoing rainfall recharge would cause water levels to recover. Model 1 indicates potential groundwater drawdowns of up to 14 m in existing boreholes close to the proposed borefields. Model 2 indicates potential groundwater drawdowns up to 3.5 m.

The additional water level drawdown may not be significant in existing deep irrigation bores which generally have approximately 100m or more of available drawdown. The drawdown effects may be compensated by installing the pump intake at a lower level in the affected well, if required.

The potential drawdown impact, according to Model 1 could be more significant in nearby stock and domestic bores which are generally shallower and have less available drawdown. Some of these bores adjacent to the production borefields could potentially “dry up” if they are less than approximately 30 m deep for the Model 1 scenario, whereas in Model 2 they would not be significantly affected.

The magnitude of stock and domestic bore impact, if any, is likely to be area-specific, depending on proximity to the borefield, permeability of the aquifer, standing water level, extraction volume, extent of surface recharge and interconnection with deeper aquifers. Overall, the potential impact would decrease with distance from the borefields as shown in Figures E-25 and E-26 for Model 1 and Model 2, respectively.

Depending on the significance of the hydraulic connection between the Lachlan River and adjacent aquifers, the cone of depression from the pumped bores is likely to increase aquifer recharge through the bed of the Lachlan River.

Lowering of the water table may suppress the groundwater mound that has developed beneath the Jemalong-Wyldes Plains area. Shallow groundwater tables are associated with dryland salinisation and reduction of the groundwater table in this area may mitigate salinisation impact during pumping. At the same time, the cone of depression from the pumping bores may induce a reversal of groundwater flow direction near the Warroo Groundwater Mound, resulting in the restoration of the original groundwater flow path northwards from the Bland Creek Palaeochannel.

A groundwater management plan would be developed and regularly reviewed/updated to monitor the impacts of mine groundwater abstraction from the borefields. Section 8 describes the proposed groundwater monitoring programme.

5.3 SALINITY TRANSPORT

The model MT3D was used to investigate possible salinity increases at the proposed borefields, using the Model 1 setup, to determine possible degradation to the quality of extracted groundwater. Coffey (2000) details the approach adopted for the modelling of salinity transport.

As a result of the lack of specific salinity information, it was not possible to calibrate the MT3D model within the scope of the investigation. However, when applied with assumptions based on available field data, the model provides a means of indicating the possible consequences for groundwater quality as a result of the proposed borefield development.

The model was run using the advection/dispersion modules with salinity represented as a conservative contaminant within the simulation. Initial concentrations were established from records monitored in April and May 1979 for bores in the vicinity of the proposed borefields and also for sites sampled in the Lachlan Formation in the area near the western boundary of the model.

The area near the western boundary was assumed to be a constant source of saline water, whereas high salinities appear to leach into the Lachlan Formation from the Cowra Formation. The salinities applied at the start of the simulation in the vicinity of the borefields were considered to be localised, instantaneous bodies of raised salinity (ie. they were not persistent as was the case of the observed concentration on the western boundary). Figure E-27 shows the initial concentrations used in the salinity modelling.

The initial condition was applied and the model was run for a 30 year simulation trial period as used in the previous flow simulations. The eastern and western borefields were operated 6 months on, 6 months off, discharging at 200 L/s.

Longitudinal dispersion was applied at 10 per day with a lateral and vertical factoring of 0.1. The dispersion routine used was the third order TVD method based on the ULTIMATE algorithm, which is a part of the MT3D package, which requires no parameters (Coffey, 2000).

Figures E-27 and E-28 show the initial concentrations used in the salinity modelling and the simulated salinity concentrations after 30 years of extraction, respectively. The western bore (PB-W2) displayed a steady decline in chloride concentration as the aquifer developed locally. Initial salinity levels of 400 mg/L decreased to less than 30 mg/L after 8 years.

The eastern bore (PB-E1) was assumed to have zero salinity concentration at the start of simulation and there were no indications from the modelling that chloride concentration would rise to detectable levels over the 30 years of extraction.

6 PUMPING REGIME

Six months sequential pumping of each alternate borefield is proposed to reduce the impact on groundwater levels in a localised extraction area. This pumping schedule was modelled by alternating pumping the proposed Eastern and Western borefields on a six month on, six month off cycle. While water level recovery is less than regional drawdown after several years of operation, localised partial water level recovery in the vicinity of the “resting” borefield is likely to reduce well interference effects and may result in increased efficiency of well performance.

Two bores in each field of three bores would be actively pumping. To reduce mutual interference effects, the holes furthest apart in each field would be the primary production bores. Typically, the “standby” bore would be located between the primary pumping bores and would only be activated in the event of breakdown or scheduled maintenance on the two production bores. Once pumping is discontinued, recharge would cause water levels to recover.

7 POTENTIAL IMPACT ON GROUNDWATER REGIME

7.1 JEMALONG PLAINS

The lowering of the water table may reduce the groundwater mound that has developed beneath the Jemalong-Wyldes Plains area. Shallow groundwater tables are associated with dryland salinisation and reduction of the groundwater table in this area may mitigate salinisation impacts during the period of pumping. At the same time, the cone of depression from the pumping bores may induce a reversal of groundwater flow direction near the Warroo Groundwater Mound, resulting in the restoration of the original groundwater flow path northwards from the Bland Creek Palaeochannel.

7.2 LACHLAN RIVER

No information is available regarding the nature of surface water losses to and river gains from groundwater. It appears likely that the Lachlan River downstream of Jemalong Weir alternates between losing and gaining states along the reach of the river. This is likely to depend on the relative levels of water in the river and local groundwater flow. During periods of flood in the Lachlan River, groundwater recharge may increase.

The potential impact of the proposed groundwater extractions on river levels would depend on the significance of the hydraulic interconnection between the shallow and deeper aquifers. A groundwater level decrease in deeper aquifers due to pumping may induce vertical infiltration from the shallow aquifer and maintain a stretch of river that recharges to the groundwater depression. The magnitude of the losses to shallow aquifers would also depend on variations in the weather, farm irrigation practice, surface soil types and slope, nature of the channel bed material and flooding events.

7.3 LAKE COWAL SYSTEM

The Cowra Formation becomes increasingly clayey to the south over the Bland Creek Palaeochannel. Grey fluviatile clays of the Cowra Formation extend to greater than 70 m over the Lachlan Formation (North Limited, 1998). The Lake Cowal hydrogeology comprises two claybound sand and gravel colluvial aquifers bounded by aquitards of clayey lacustrine sediments. The sediments are underlain by the Lake Cowal Volcanics which is fractured and oxidised on its upper surface and comprises a third shallow aquifer.

Based on Coffey (1995), there is no direct hydraulic interconnection between Lake Cowal and the shallow aquifers and groundwater does not discharge into the lake under dry lake conditions.

Hydrological investigations for Lake Cowal suggest that the lake bed is impermeable to vertical infiltration of lake water (North Limited, 1998). The long term vertical permeability of the lake bed is unknown but is assessed to be low due to the fine-grained lacustrine sediments. Lowering of the piezometric surface in the Lachlan Formation in the Bland Creek Palaeochannel is not anticipated to affect the water level within Lake Cowal or Lake Nerang-Cowal.

The proposed Cowal Gold Mine would source process make-up water from a proposed borefield situated in the Lachlan Formation within the Bland Creek Palaeochannel, east of the mine (Coffey, 1995). The Syerston borefield is located approximately 25 km north of the Cowal Mine, as shown in Figure E-1. Model 1 indicates that the drawdown of water levels arising from extraction at the proposed Syerston Project Eastern and Western borefields may result in 1 m to 5 m of additional groundwater level drawdowns in the proposed Cowal Mine production borefield, whilst Model 2 indicates no discernible effect.

7.4 BOGANDILLON SWAMP

Bogandillon Swamp (Figure E-1) is reported as receiving water from overflow of the Nerang-Cowal system (North Limited, 1998). The Forbes hydrogeological map places the swamp in a low groundwater occurrence area (0.05 L/s to 0.5 L/s) and the source of groundwater is reported to be the shallow subsurface aquifer (Hawkes, 1998). This suggests that Bogandillon Swamp may lie outside the area of significant development of Cowra Formation sediments and overlies shallow bedrock. The Lachlan River Palaeochannel and infilled Lachlan Formation sediments do not occur in this area. Bogandillon Swamp is approximately 25 km from the proposed Syerston Western borefield. Groundwater extraction from the borefield is unlikely to significantly affect groundwater levels at Bogandillon Swamp as the bedrock high on the Bogandillon Range forms a no-flow barrier between the Swamp and the borefields.

8 MONITORING RECOMMENDATIONS

Requirements for monitoring the hydrogeological system that should be included in a borefield management plan, include:

- bore census (including collation of all relevant quality, quantity, yield, depth and usage data) of all bores within a 10 km radius of the Syerston Project borefields prior to commencement of groundwater extractions.
- daily rainfall at the borefield;
- continuous groundwater level monitoring in:
  - production bores;

  - standby bores; and
  - borefield observation piezometers, including PB-W1, PB-W2 and PB-E1;
- quarterly monitoring of pH, electrical conductivity, redox potential, CO_2, bicarbonate and temperature at the wellhead;
- monthly groundwater level monitoring and bore usage reports should be conducted in selected regional bores within a 10 km radius of the borefields;
- annual monitoring in ten bores within a 10 km radius of the borefields of water quality from each production bore. The samples should be analysed for the following parameters:
  - pH, electrical conductivity, redox potential (Eh), temperature and dissolved CO_2 at the time of sampling;
  - suspended solids, total dissolved solids, total alkalinity and methyl orange alkalinity;
  - major cations (Ca, Mg, Na, K) and major anions (Cl, SO_4, F, NO_3);
  - metals including Fe^{2+}, Fe^{3+} and Mn on filtered and acid preserved samples; and
- annual groundwater usage and level monitoring in selected regional bores within a 20 km radius of the borefields.

9 CONCLUSIONS

Based on the fieldwork programme and computer modelling, the following conclusions are indicated:

- the Lachlan Formation is capable of supplying the required yield of 200 L/s over a 30 year period;
- the required groundwater yield can be derived from two borefields of three production bores, each, with two bores in one borefield pumping at any one time. The pumping yield of the individual bores would be in the order of 100 L/s;
- the groundwater quality in the Lachlan alluvials is considered suitable for the proposed use;
- the proposed extraction rate of 200 L/s is greater than the aquifer’s rainfall recharge rate. This would result in a depletion of the aquifer during the extraction period;
- after 30 years of extraction the modelling predicted a drawdown of about 3-4 m around the aquifer boundaries in Model 1 and up to 0.5 m with Model 2. The drawdown in the vicinity of the production borefields was predicted to be up to approximately 3.5 m to 14 m, respectively;
- the drawdown resulting from the proposed extraction occurs in association with drawdown from other groundwater users in the area;
- the water level drawdown impact on existing irrigation stock and domestic bores can generally be managed by lowering the existing pump sets to compensate for lower water levels;
- the impact on shallow bores in the Cowra Formation is likely to be variable, depending on the depth of the screened interval and the bore’s proximity to the Syerston borefield;
- the modelled impact on the six nearest bores indicates that after 30 years of pumping the water level drawdown would vary from 5 m to 15 m for Model 1 and less than 3.5 m for Model 2;
- increased recharge from the Lachlan River to the groundwater system may result from pumping in the proposed borefields; and

- no groundwater impacts on Lake Cowal, Nerang Cowal or Bogandillon Swamp are predicted due to the aquifers associated with these systems generally being hydraulically isolated from the Lachlan aquifer system.

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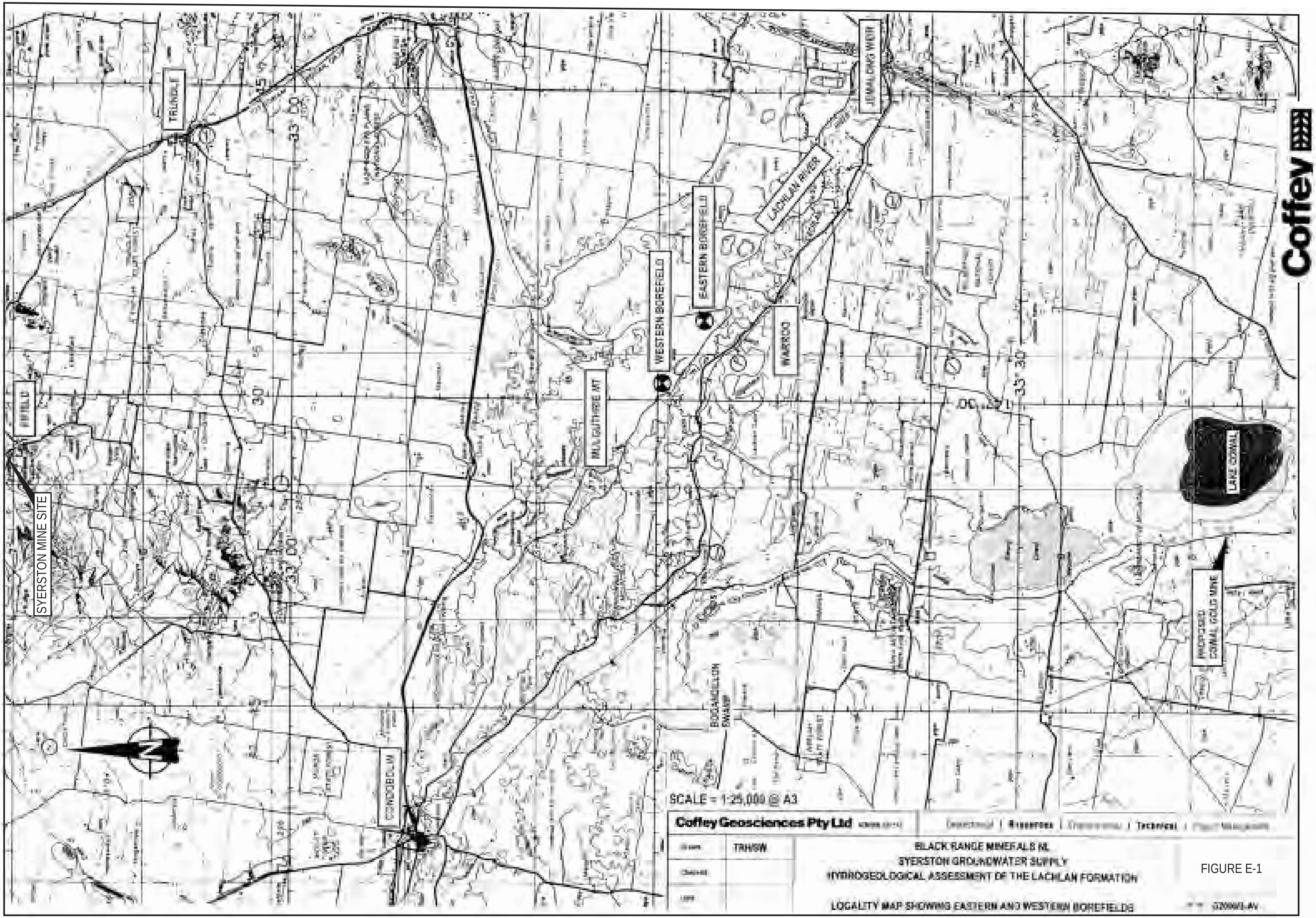
FIGURES



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Geotechnical | Resources | Environmental | Technical | Project Management

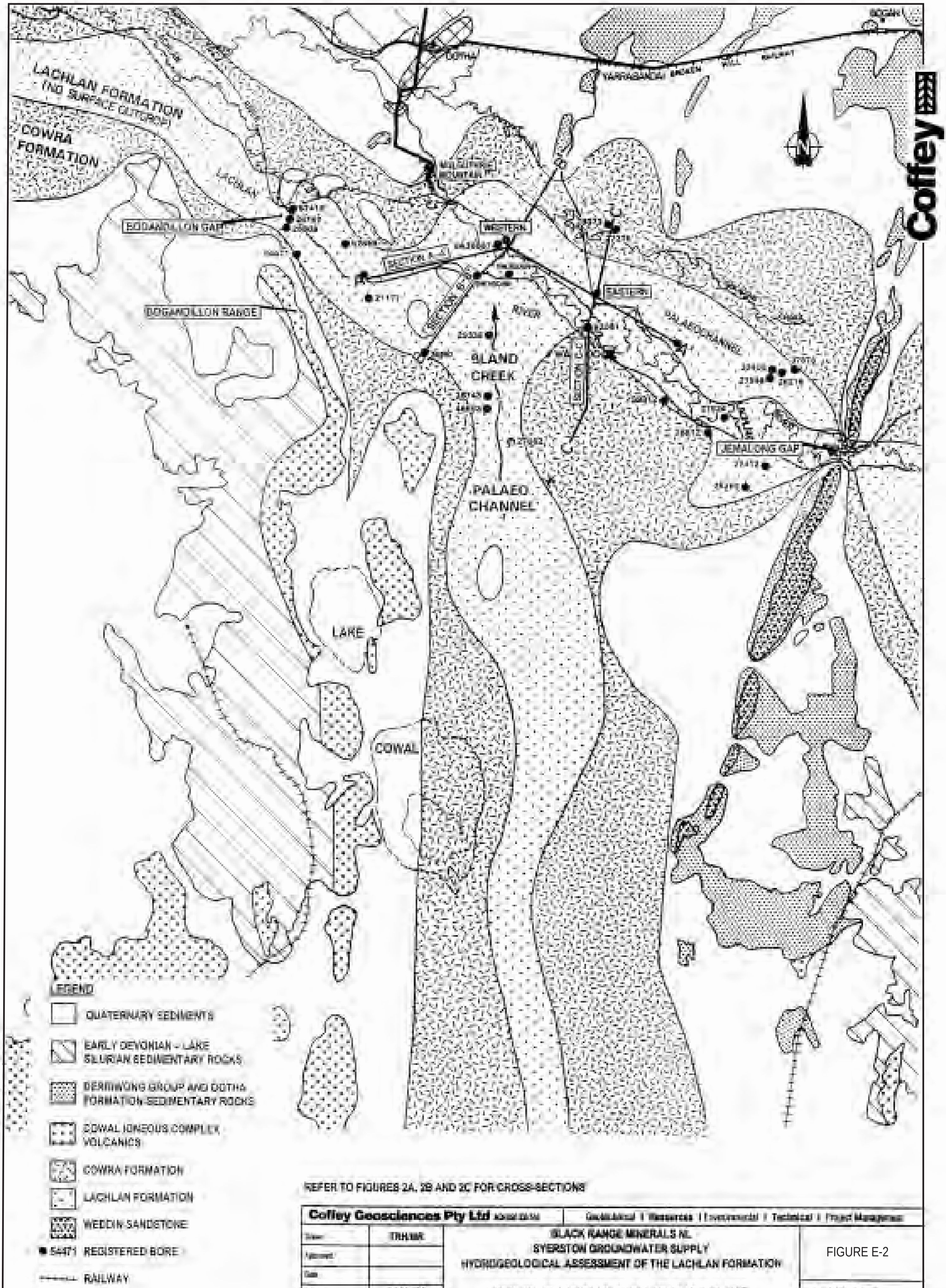
Drawn	TRH/SW
Checked	
Date	

BLACK RANGE MINERALS NL
SYERSTON GROUNDWATER SUPPLY
HYDROGEOLOGICAL ASSESSMENT OF THE LACHLAN FORMATION

LOCALITY MAP SHOWING EASTERN AND WESTERN BOREFIELDS

FIGURE E-1

BRM-98-01-WS_001A



Coffey

REFER TO FIGURES 2A, 2B AND 2C FOR CROSS-SECTIONS

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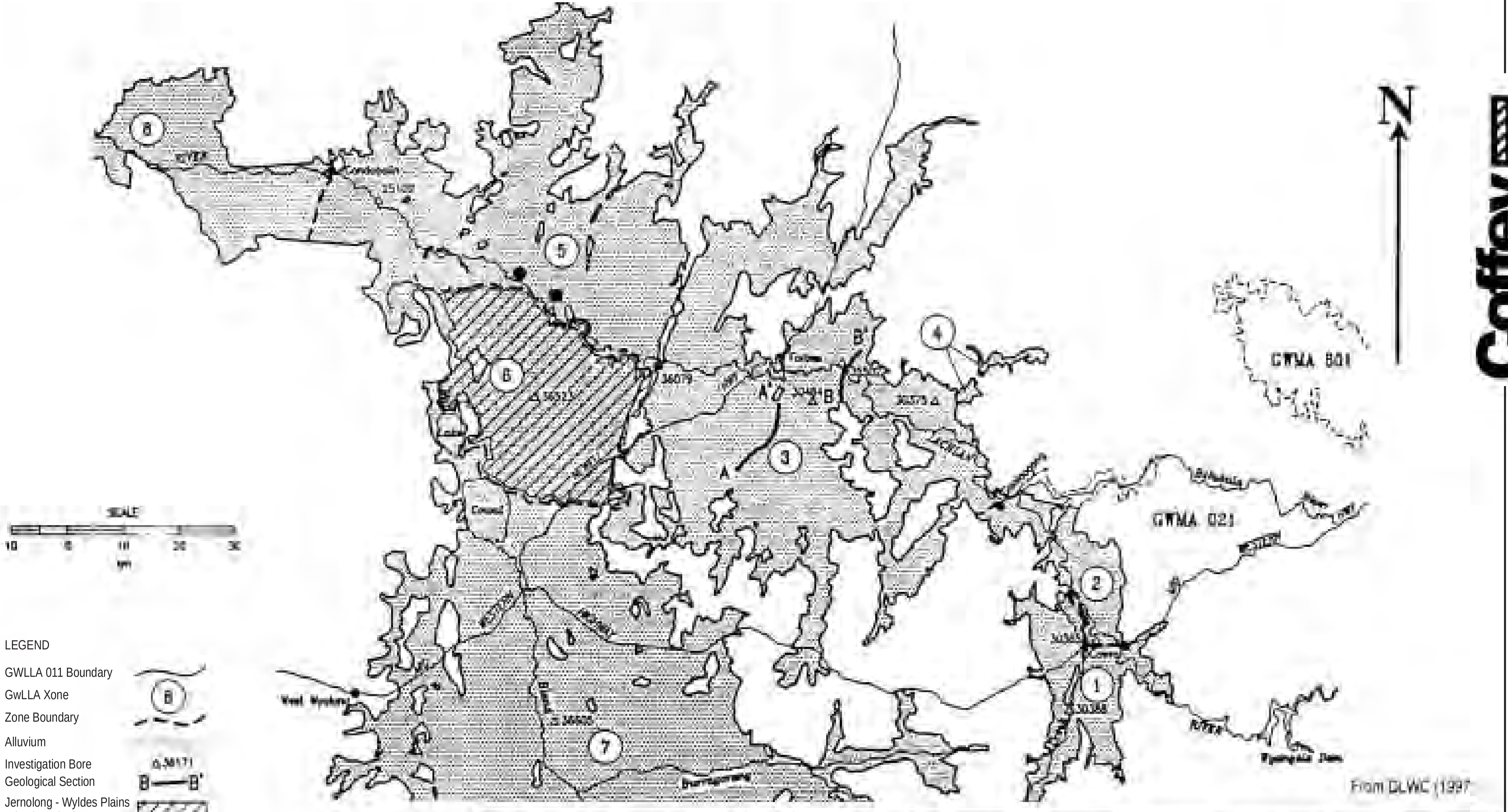
Drawn	TRH/MR	BLACK RANGE MINERALS NL SYERSTON GROUNDWATER SUPPLY HYDROGEOLOGICAL ASSESSMENT OF THE LACHLAN FORMATION	FIGURE E-2
Approved			
Date			
Scale	1:250,000	COMBINED HYDROGEOLOGICAL / GEOLOGICAL MAP	Job no: G20060/4V



From DLWC (1997

LEGEND

- GWLLA 011 Boundary
- GwLLA Xone
- Zone Boundary
- Alluvium
- Investigation Bore
- Geological Section B—B'
- Jernolong - Wyldes Plains Irrigation District ▨
- ● Western Borefield
- ■ Eastern Borefield
- ▨ Groundwater Management Area 11

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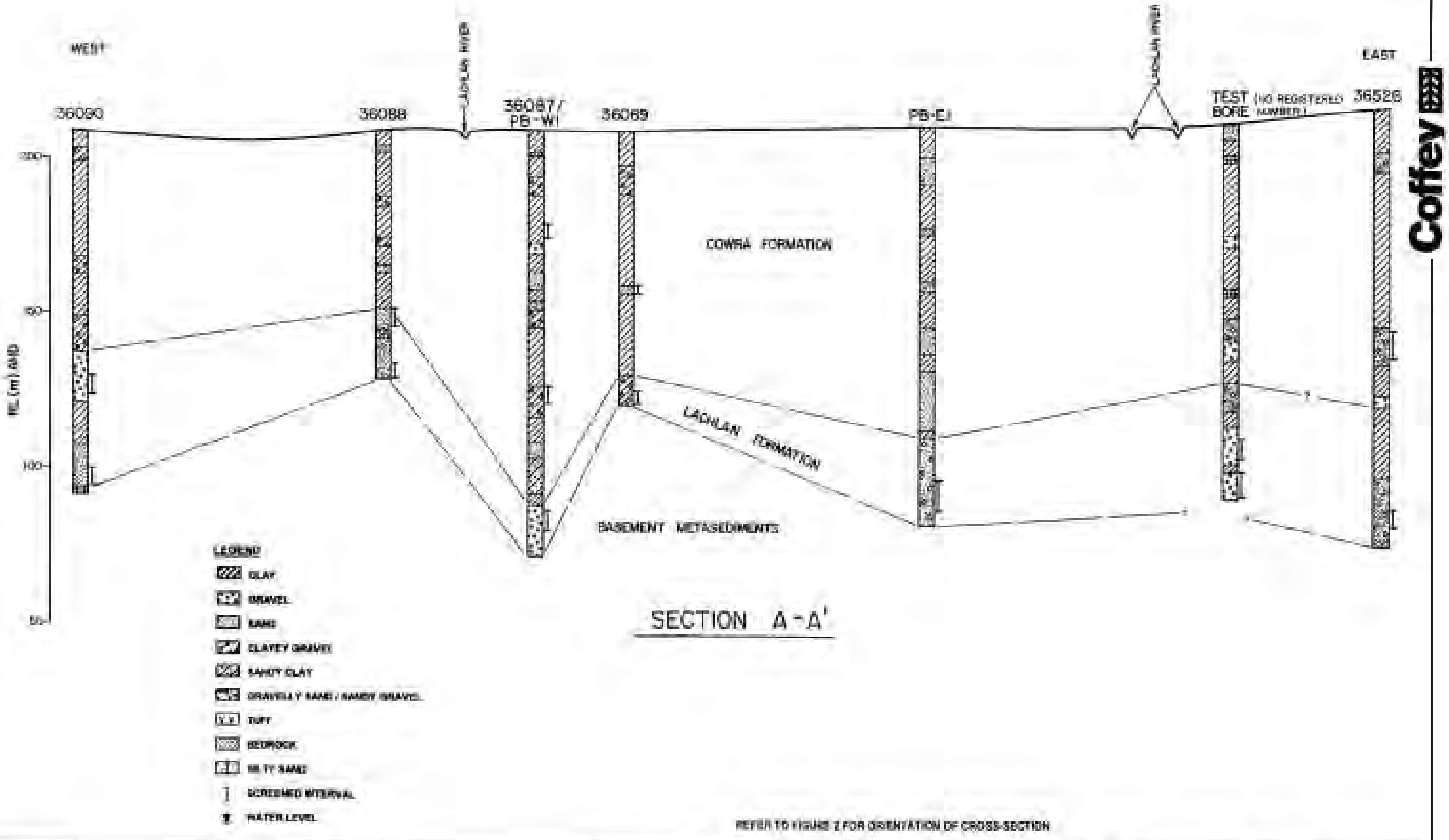
Geotechnical | Resources | Environmental | Technical | Project Management

Drawn	TRH
Approved	
Date	17/01/00
Scale	as shown

BLACK RANGE MINERALS NL
SYERSTON GROUNDWATER SUPPLY
HYDROGEOLOGICAL ASSESSMENT OF THE LACHLAN FORMATION
DEPARTMENT OF LAND AND WATER CONERVATION
GROUNDWATER MANAGEMENT ZONES

FIGURE E-3

Job no. G2000/3-AV



SECTION A - A'

REFER TO FIGURE 2 FOR ORIENTATION OF CROSS-SECTION

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Geotechnical | Resources | Environmental | Technical | Project Management

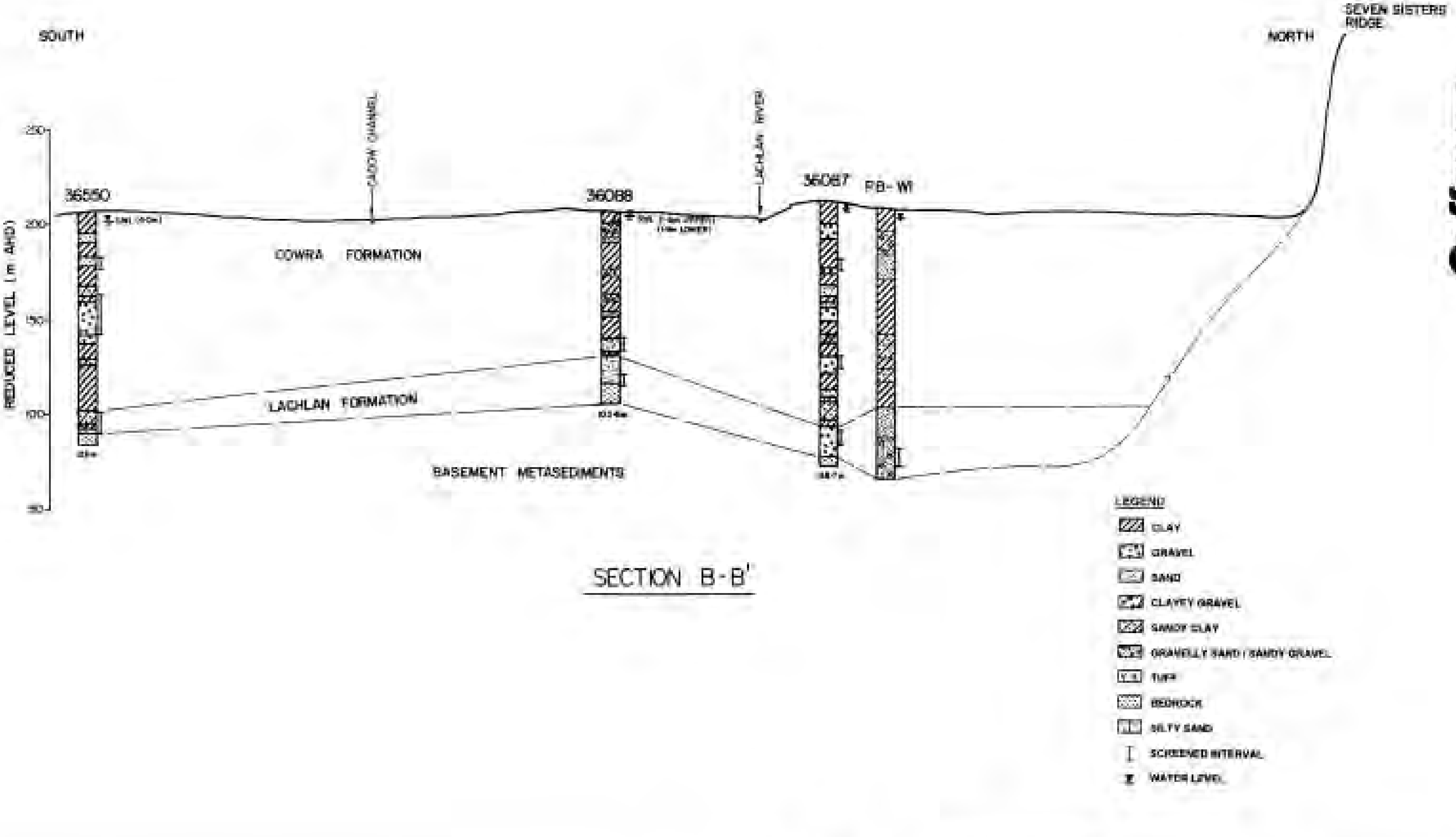
HORIZONTAL
Scale (metres)
0 1000

Drawn TRDAVS
Checked
Date

BLACK RANGE MINERALS NL
SYERSTON GROUNDWATER SUPPLY
HYDROGEOLOGICAL ASSESSMENT OF THE LACHLAN FORMATION

INTERPRETED GEOLOGICAL CROSS-SECTION A-A'

FIGURE E-4



SECTION B-B'

REFER TO FIGURE 2 FOR ORIENTATION OF CROSS-SECTION

Coffey Geosciences Pty Ltd

Geotechnical | Resources | Environmental | Technical | Project Management

HORIZONTAL
0 3000
Scale (metres)

Revision

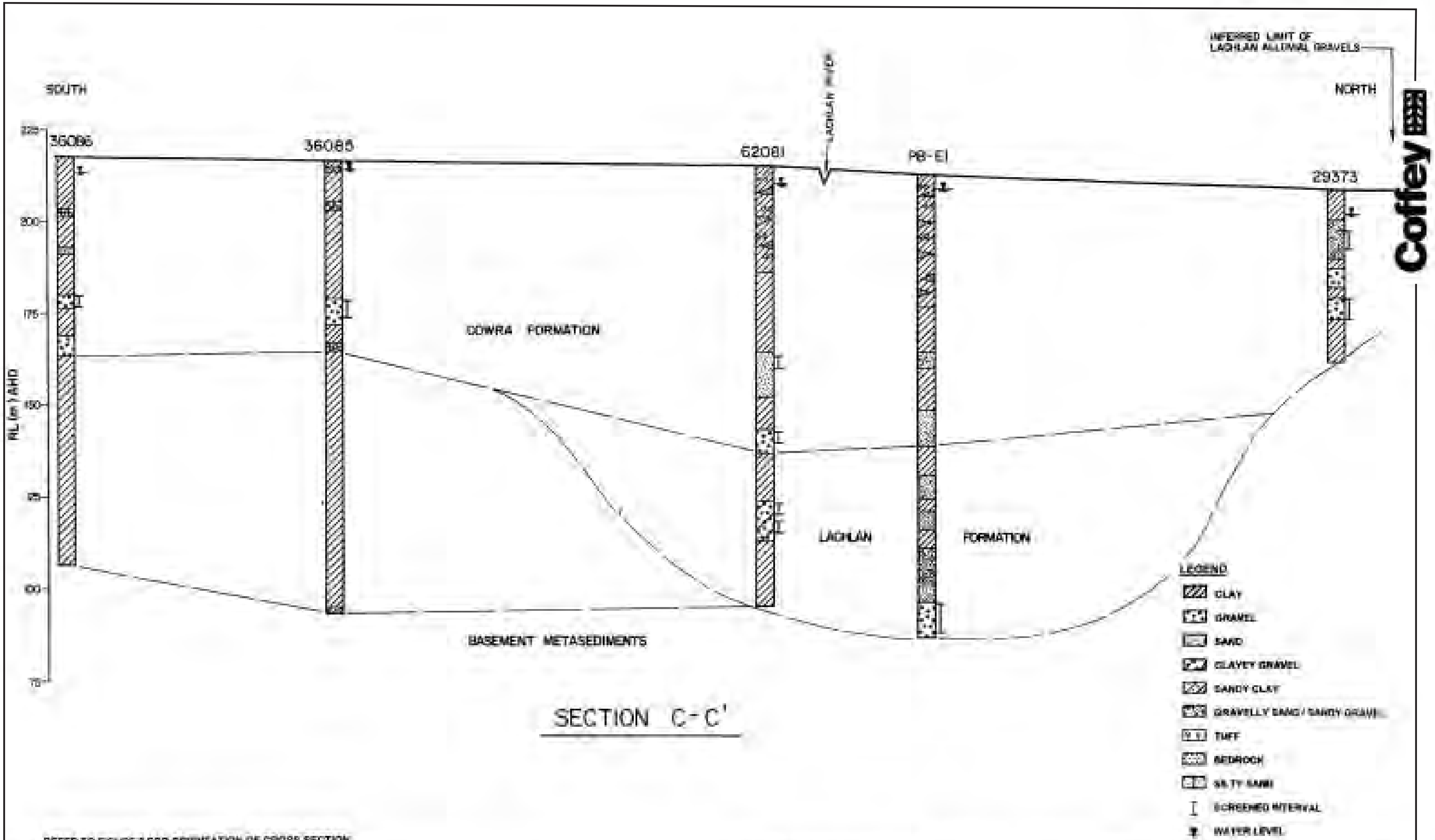
Drawn: TR/MR
Checked:
Date:

BLACK RANGE MINERALS NL
SYERSTON GROUNDWATER SUPPLY
HYDROGEOLOGICAL ASSESSMENT OF THE LACHLAN FORMATION

INTERPRETED GEOLOGICAL CROSS-SECTION B-B'

FIGURE E-5

Job no: G20803-AV



REFER TO FIGURE 2 FOR ORIENTATION OF CROSS-SECTION

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HORIZONTAL	Revision	Description	Drawn	Approved	Date		
0 — 2000 Scale (metres)						Drawn	TR/GMR
						Checked	
						Date	

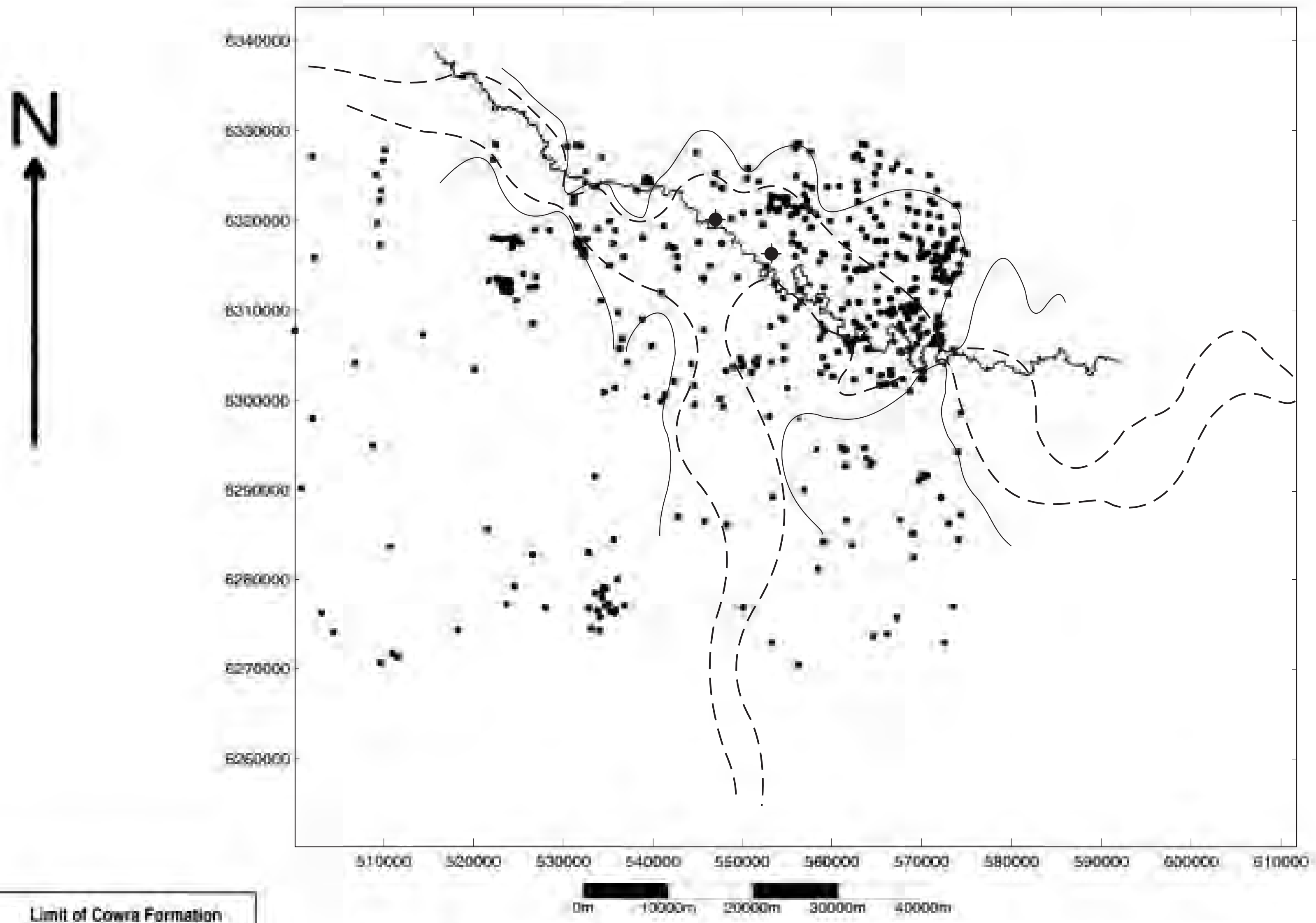
BLACK RANGE MINERALS NL
SYERSTON GROUNDWATER SUPPLY
HYDROGEOLOGICAL ASSESSMENT OF THE LACHLAN FORMATION

INTERPRETED GEOLOGICAL CROSS-SECTION C-C'

FIGURE E-6

Job no: G200/3-AV

Coffey



Coffey Geosciences Pty Ltd ACN 056 335 516

Geotechnical | **Resources** | Environmental | **Technical** | Project Management

Drawn TRH

Approved

Date Jan 2000

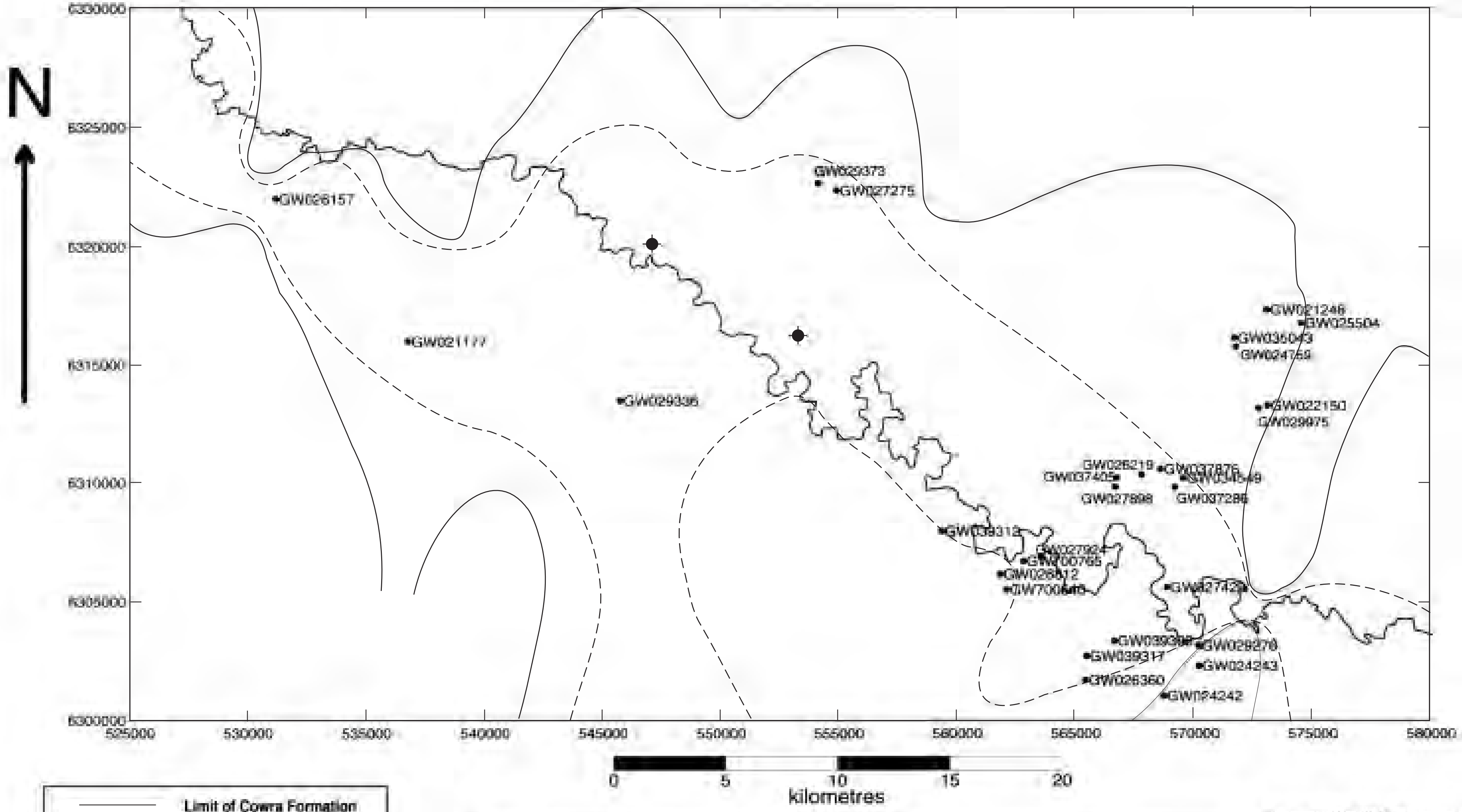
Scale as shown

BLACK RANGE MINERALS NL
SYERSTON GROUNDWATER SUPPLY
HYDROGEOLOGICAL ASSESSMENT OF THE LACHLAN FORMATION

LOCATION OF REGISTERED
BOREHOLES LESS THAN 50m DEEP

FIGURE E-7

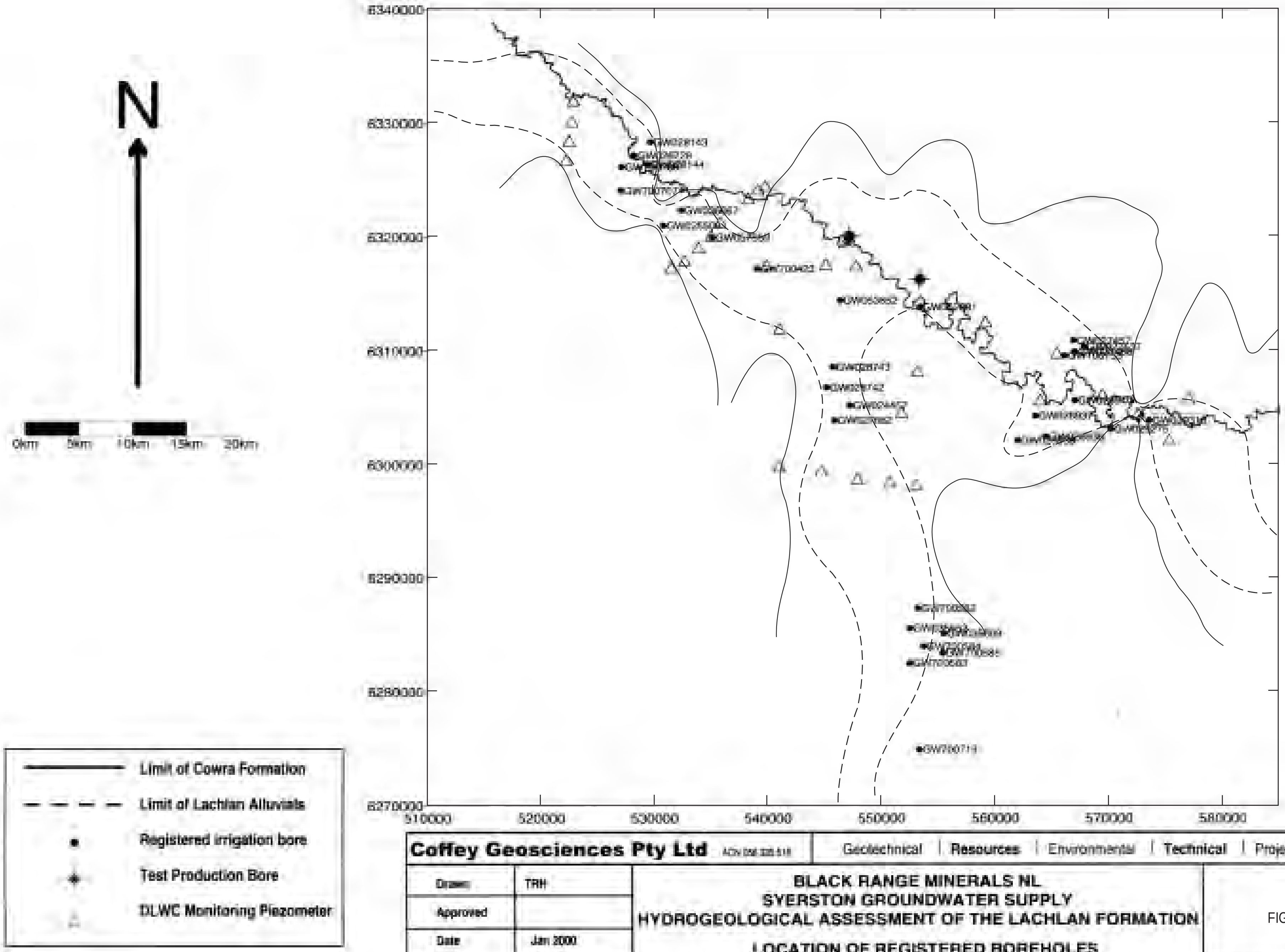
job no: G2000/3-AV



Coffey

I:/grndwatr/g2000/g2000.3/figures/cowra_users.m

Coffey Geosciences Pty Ltd ACN 056 335 516	Geotechnical | **Resources** | Environmental | **Technical** | Project Management	
Drawn: TRH Approved: Date: Jan 2000 Scale: 1:250000	BLACK RANGE MINERALS NL SYERSTON GROUNDWATER SUPPLY HYDROGEOLOGICAL ASSESSMENT OF THE LACHLAN FORMATION **LOCATION OF REGISTERED IRRIGATION** **BOREHOLES IN THE COWRA FORMATION**	FIGURE E-8 job no: G2000/3-AV



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Geotechnical | Resources | Environmental | Technical | Project Management

Drawn	TRH
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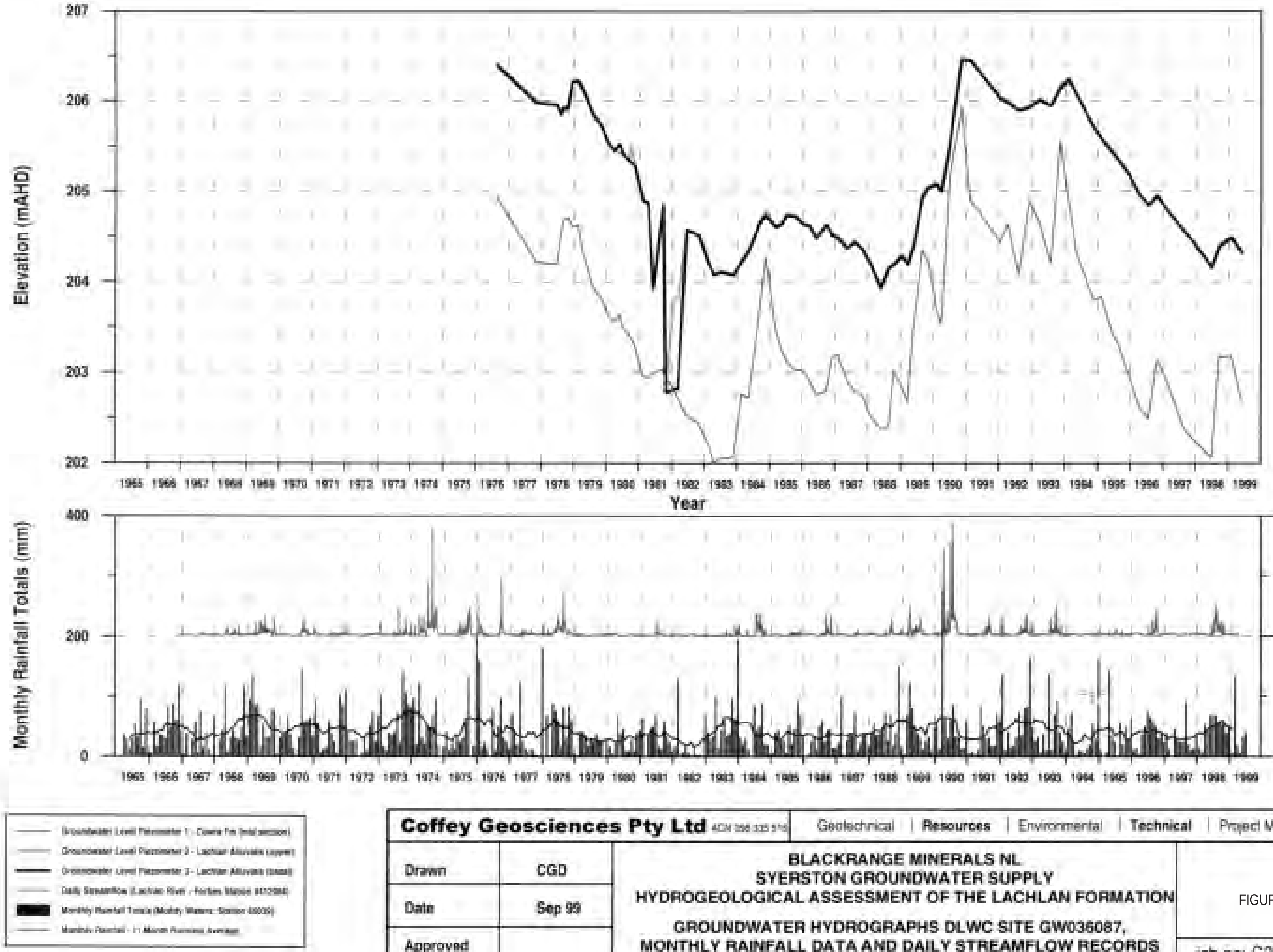
Date	Jan 2000
Scale	as shown

BLACK RANGE MINERALS NL
SYERSTON GROUNDWATER SUPPLY
HYDROGEOLOGICAL ASSESSMENT OF THE LACHLAN FORMATION

LOCATION OF REGISTERED BOREHOLES
INTERSECTING THE LACHLAN FORMATION

FIGURE E-9

job no: G2000/3-AV



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Geotechnical | Resources | Environmental | Technical | Project Management

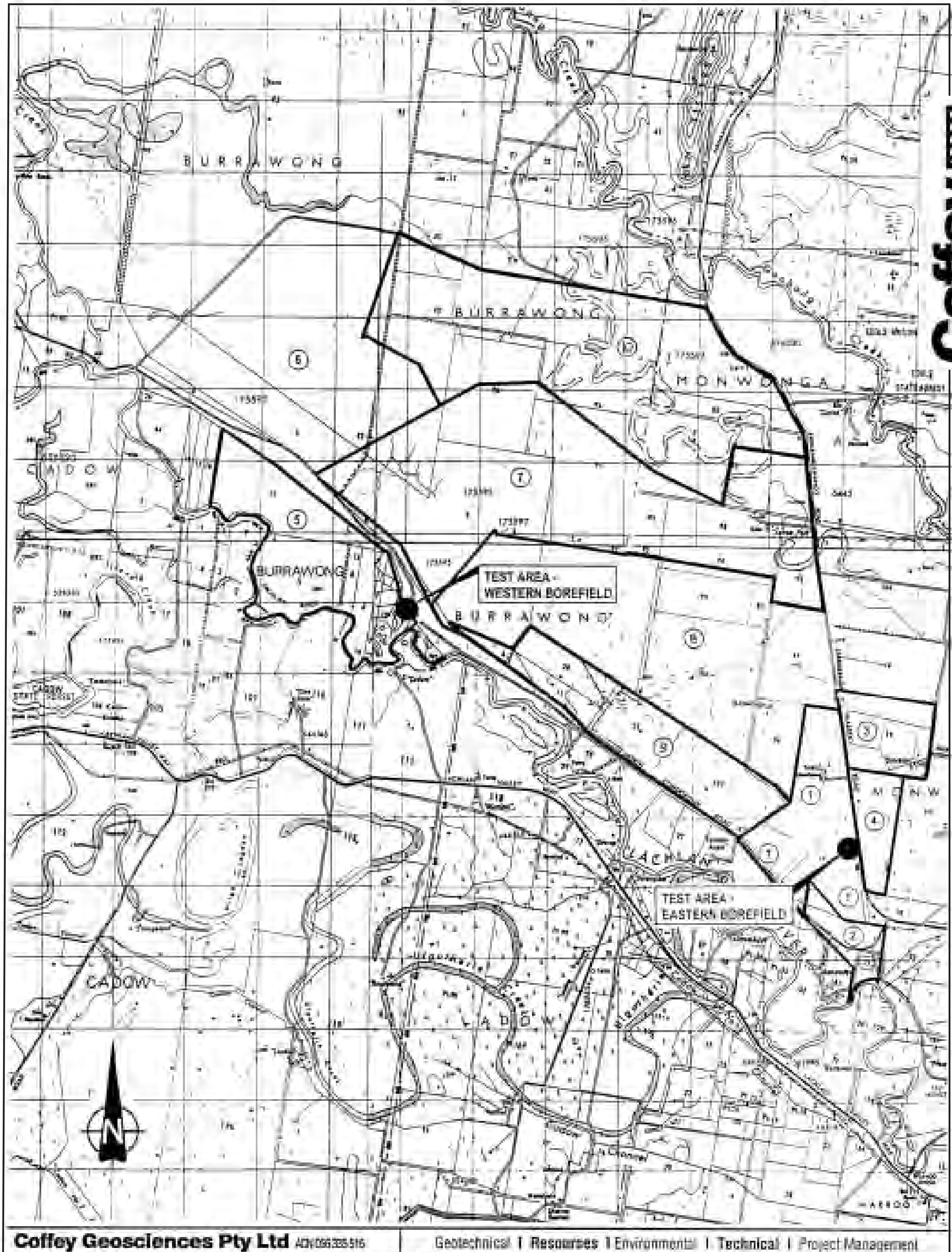
Drawn	CGD
Date	Sep 99
Approved	

BLACKRANGE MINERALS NL
SYERSTON GROUNDWATER SUPPLY
HYDROGEOLOGICAL ASSESSMENT OF THE LACHLAN FORMATION

GROUNDWATER HYDROGRAPHS DLWC SITE GW036087,
MONTHLY RAINFALL DATA AND DAILY STREAMFLOW RECORDS

FIGURE E-10

job no: G2000/3-AV



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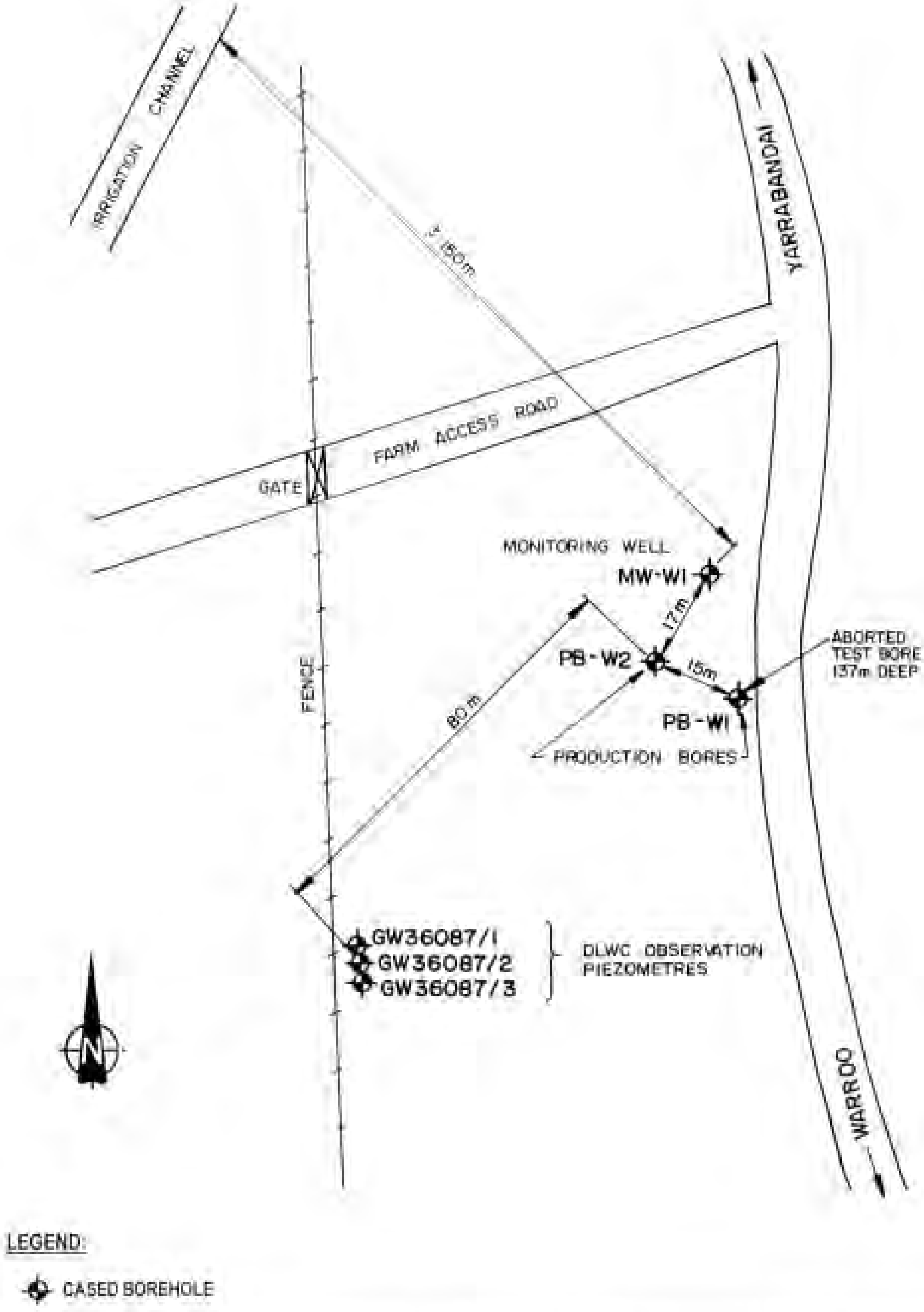
Geotechnical | Resources | Environmental | Technical | Project Management

Drawn	TRH/MR	BLACK RANGE MINERALS NL SYERSTON GROUNDWATER SUPPLY HYDROGEOLOGICAL ASSESSMENT OF THE LACHLAN FORMATION	FIGURE E-11
Approved			
Date			
Scale	1:50,000	LAND HOLDERS AT EASTERN AND WESTERN BOREFIELDS	Job no G2000/3-AV

BRM-98-01-WS_011A



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Geotechnical | **Resources** | Environmental | **Technical** | Project Management

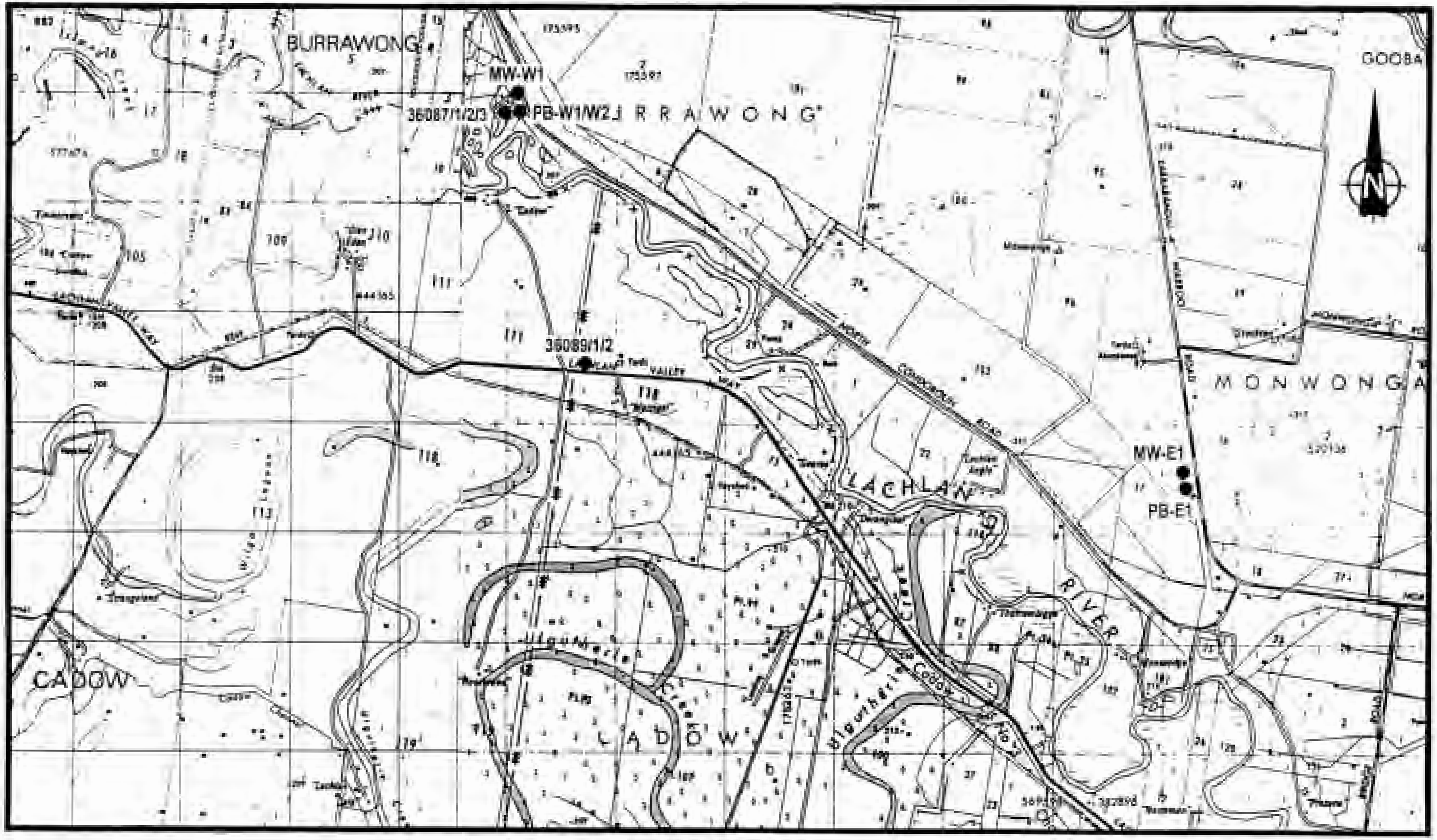
Drawn	TRR/MR
Approved	
Date	
Scale	NTS

BLACK RANGE MINERALS NL
LACHLAN ALLUVIALS GROUNDWATER STUDY

WESTERN BOREFIELD SKETCH MAP

FIGURE E-12

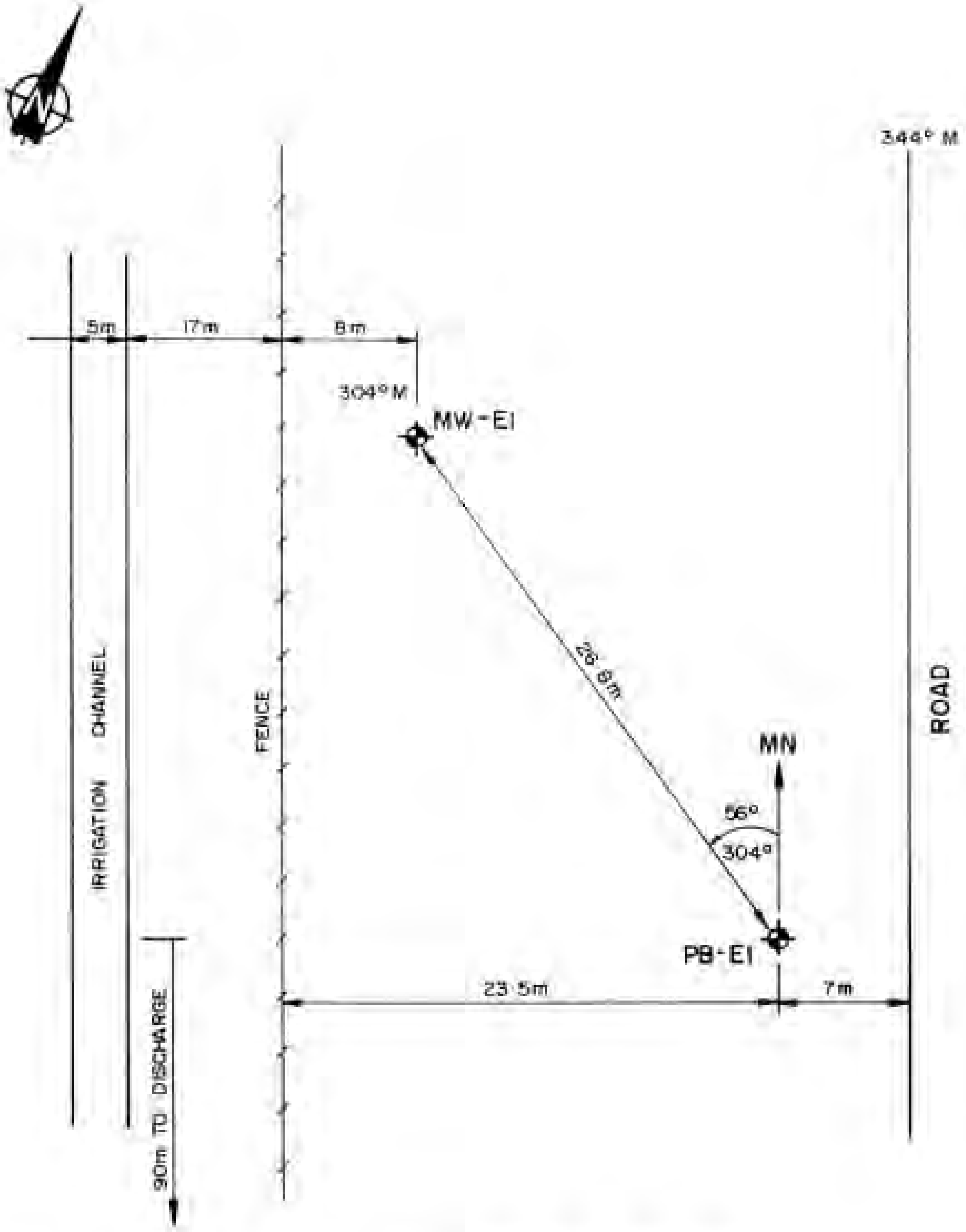
Job no G2000/3



Coffey

FOR LOCATION OF STOCK, DOMESTIC AND
IRRIGATION BORES SEE FIGURES 5, 6 & 7

Coffey Geosciences Pty Ltd ACN 056 335 516		Geotechnical | Resources | Environmental | Technical | Project Management	
Drawn	TRH/SW	BLACK RANGE MINERALS NL SYERSTON GROUNDWATER SUPPLY HYDROGEOLOGICAL ASSESSMENT OF THE LACHLAN FORMATION	FIGURE E-13
Approved			
Date			
Scale	1:50,000	MONITORED BORES – WESTERN BOREFIELD TEST	Job no: G2000/3-AV



BEARING OF HOWARDS STOCK BORE FROM PB-E1 : 329° Mag

LEGEND:

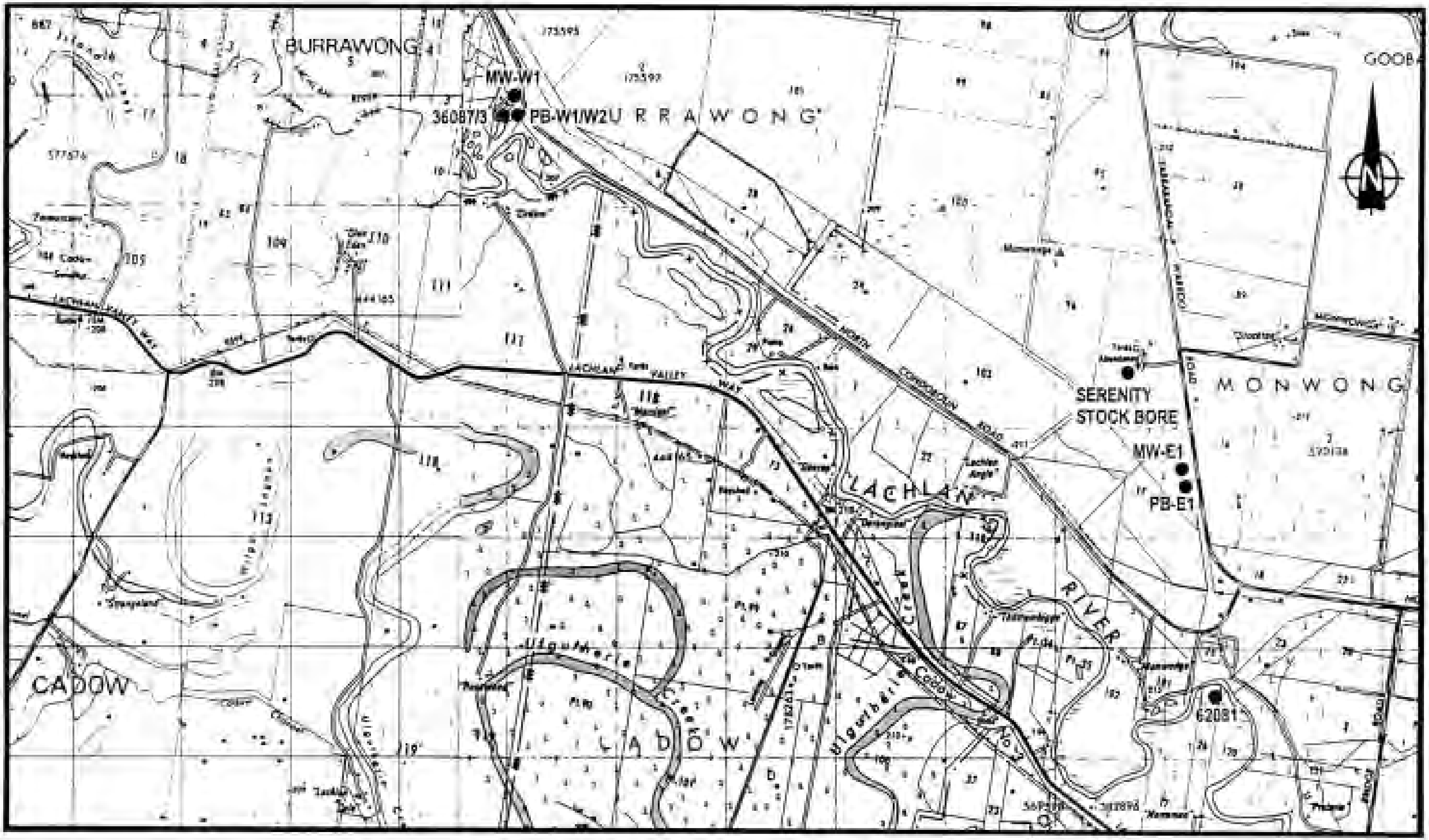
- ⊕ CASED BOREHOLE
- ⊕ UNCASED BOREHOLE

Coffey Geosciences Pty Ltd [illegible]

Geotechnical | **Resources** | Environmental | **Technical** | Project Management

Drawn	TRH/MR	BLACK RANGE MINERALS NL LACHLAN ALLUVIALS GROUNDWATER STUDY	FIGURE E-14
Approved			
Date			
Scale	NTS	EASTERN BOREFIELD SKETCH MAP	Job no: G2000/3

BRM-98-01-WS_014A



FOR LOCATION OF STOCK, DOMESTIC AND
IRRIGATION BORES SEE FIGURES 5, 6 & 7

Coffey Geosciences Pty Ltd ACN 056 335 516

Geotechnical | Resources | Environmental | Technical | Project Management

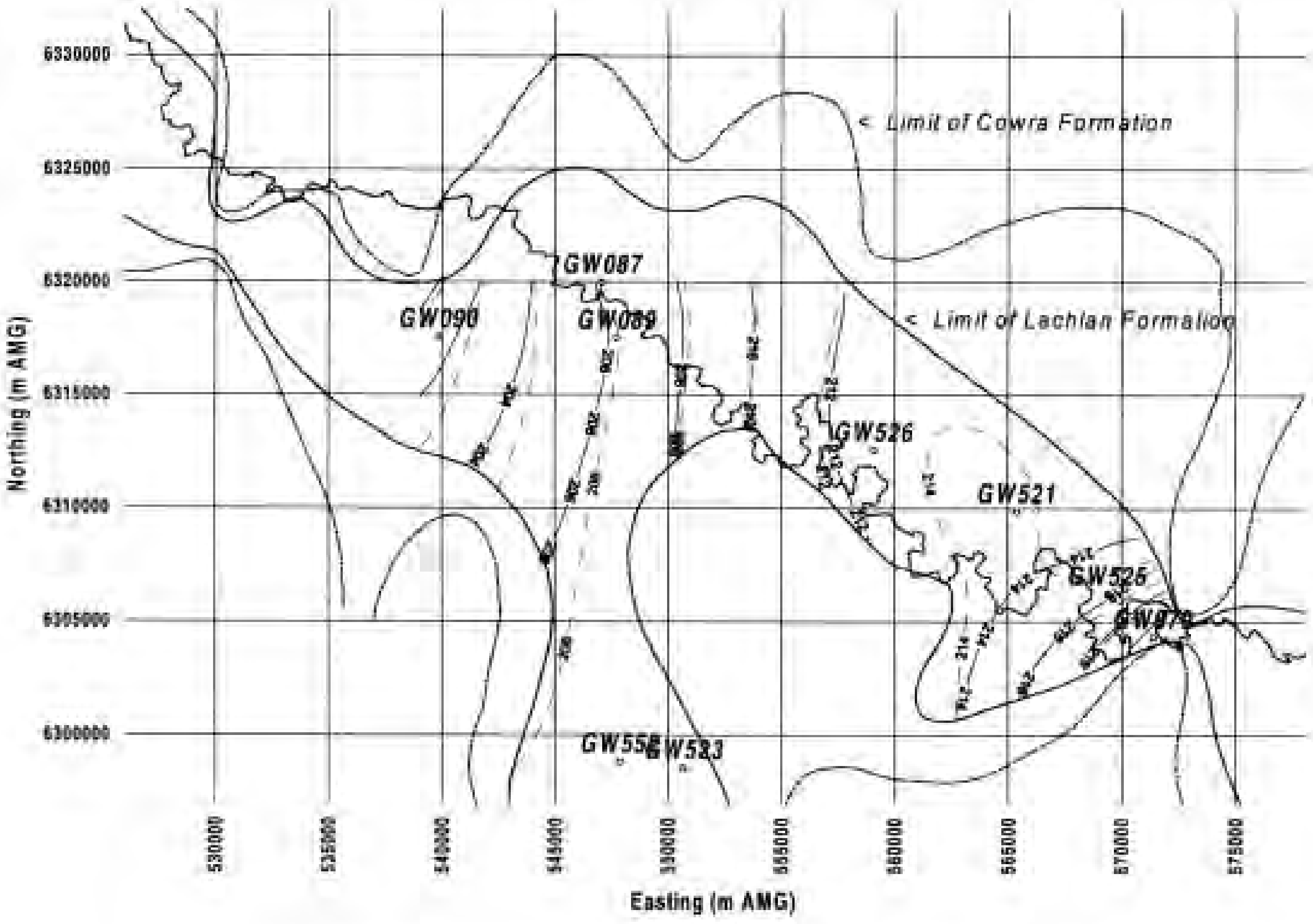
Drawn	TRH/SW
Approved	
Date	
Scale	1:50,000

BLACK RANGE MINERALS NL
SYERSTON GROUNDWATER SUPPLY
HYDROGEOLOGICAL ASSESSMENT OF THE LACHLAN FORMATION

MONITORED BORES – EASTERN BOREFIELD TEST

FIGURE E-15

Job no. G2000/3-AV



- - - Observed Head in the Lachlan Formation (mAHD)

—— Modelled Head in the Lachlan Formation (mAHD)

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Drawn JSR

Approved

Date Mar/2000

Scale (as for grid)

BLACK RANGE MINERALS AUSTRALIA PTY LTD

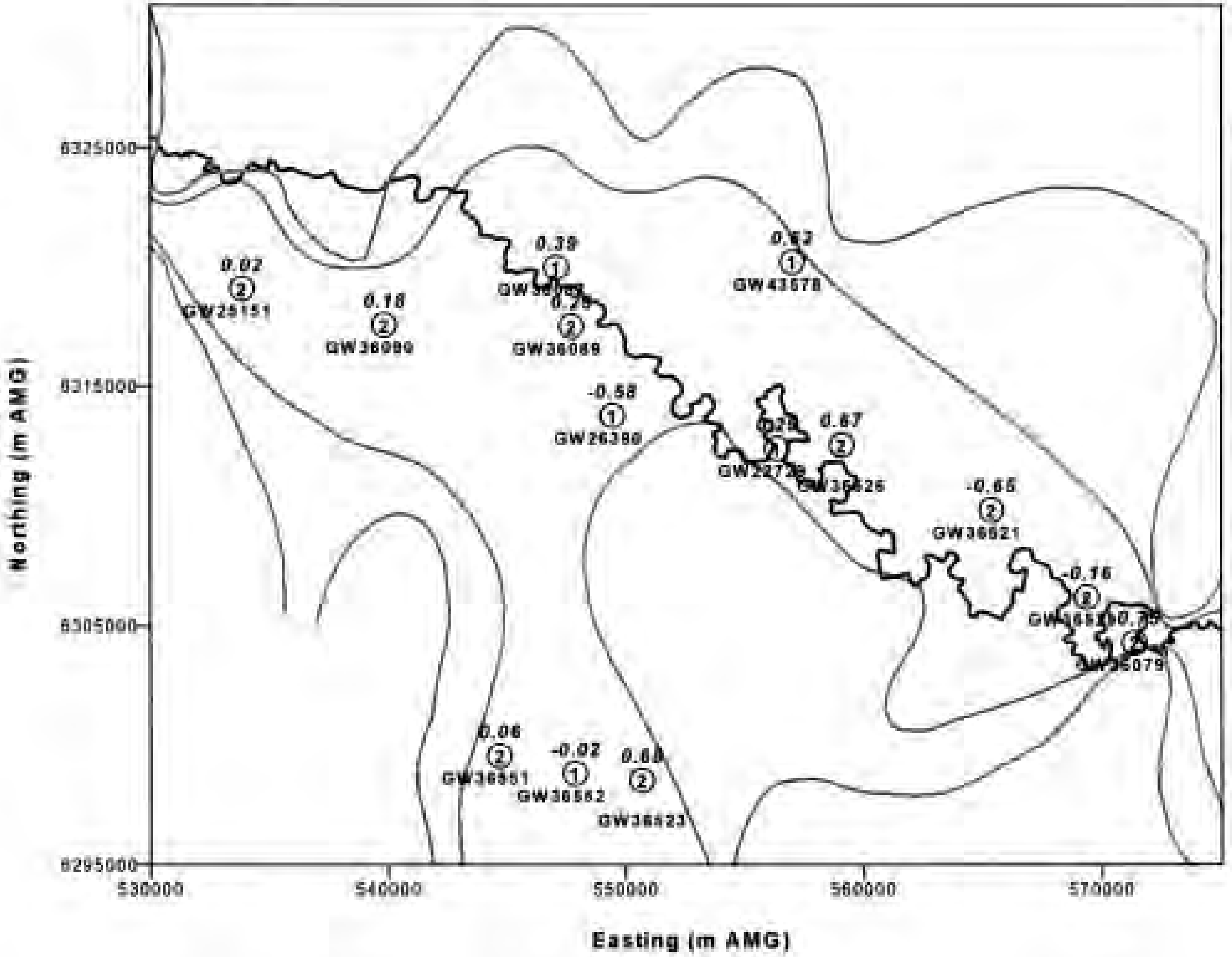
LACHLAN RIVER GROUNDWATER MODEL

STEADY STATE MODEL CALIBRATION

MODEL 1

FIGURE E-16

job no: G2000/3



LEGEND
1 Cowra Aquifer
2 Lachlan Aquifer
○ Monitoring Bore Location

Coffey Partners International Pty Ltd ACN 003 692 019 | Geotechnical | Resources | Environmental | Technical | Project Management

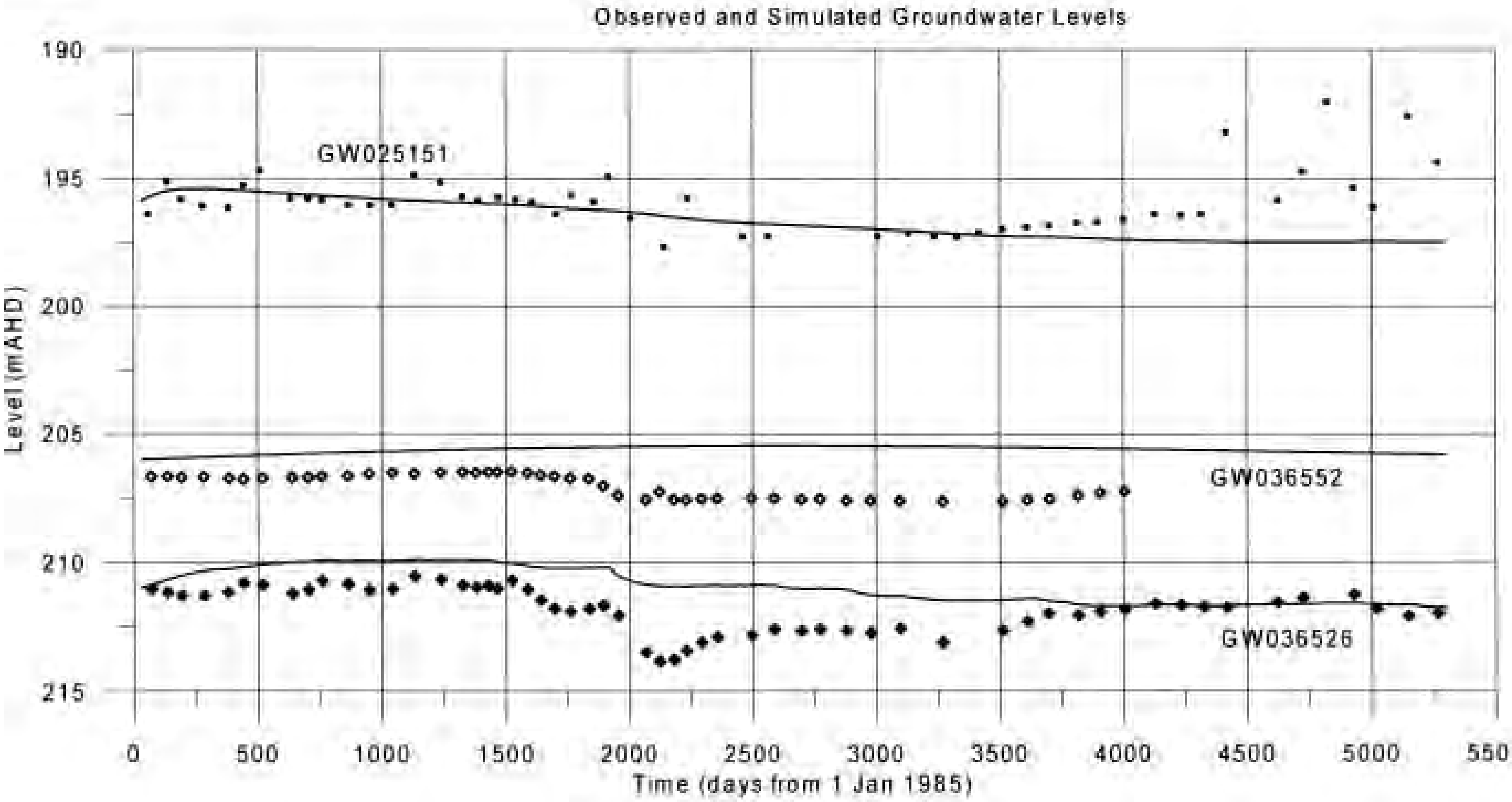
Drawn	MRG
Approved	
Date	Aug 2000
Scale	(as for grid)

BLACK RANGE MINERALS AUSTRALIA PTY LTD
LACHLAN RIVER GROUNDWATER MODEL

STEADY-STATE CALIBRATION RESIDUAL HEADS (m)
MODEL 2

FIGURE E-17

job no: G2000/3



Coffey

Coffey Geosciences Pty Ltd ACN [illegible]

Geotechnical | Resources | Environmental | Technical | Project Management

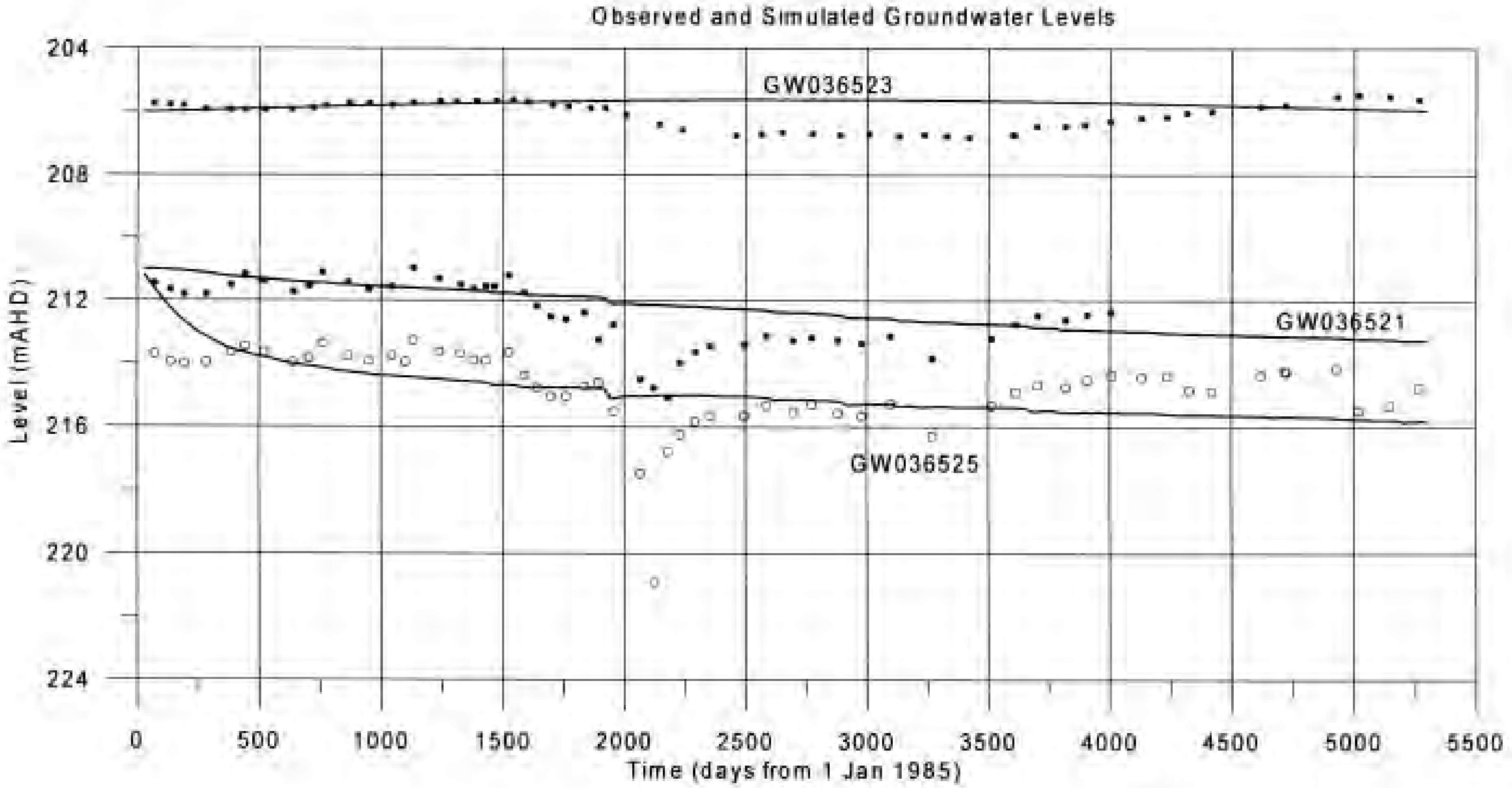
Drawn	JSR
Date	Mar/2000
Approved	

BLACKRANGE MINERALS PTY LTD
LACHLAN RIVER GROUNDWATER MODEL

OBSERVED AND SIMULATED GROUNDWATER LEVELS
FOR GW025151, GW036552, AND GW036526
MODEL 1

FIGURE E-18

job no: G2000/3



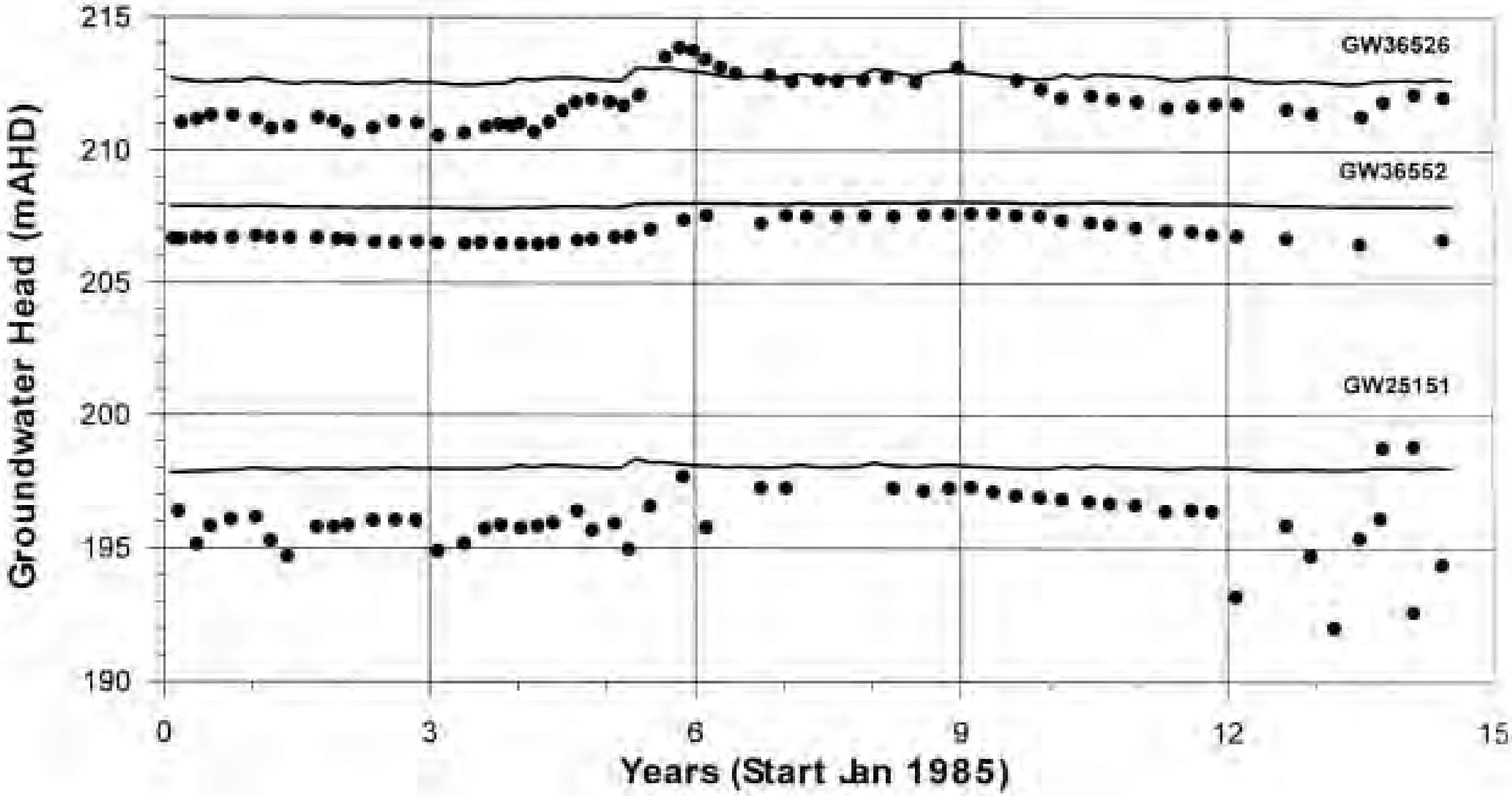
Coffey Geosciences Pty Ltd ACN 056 335 516 | Geotechnical | Resources | Environmental | Technical | Project Management

Drawn	JSR
Date	Mar/2000
Approved	

BLACKRANGE MINERALS PTY LTD
LACHLAN RIVER GROUNDWATER MODEL
OBSERVED AND SIMULATED GROUNDWATER LEVELS
FOR GW036523, GW036521, AND GW036525
MODEL 1

FIGURE E-19

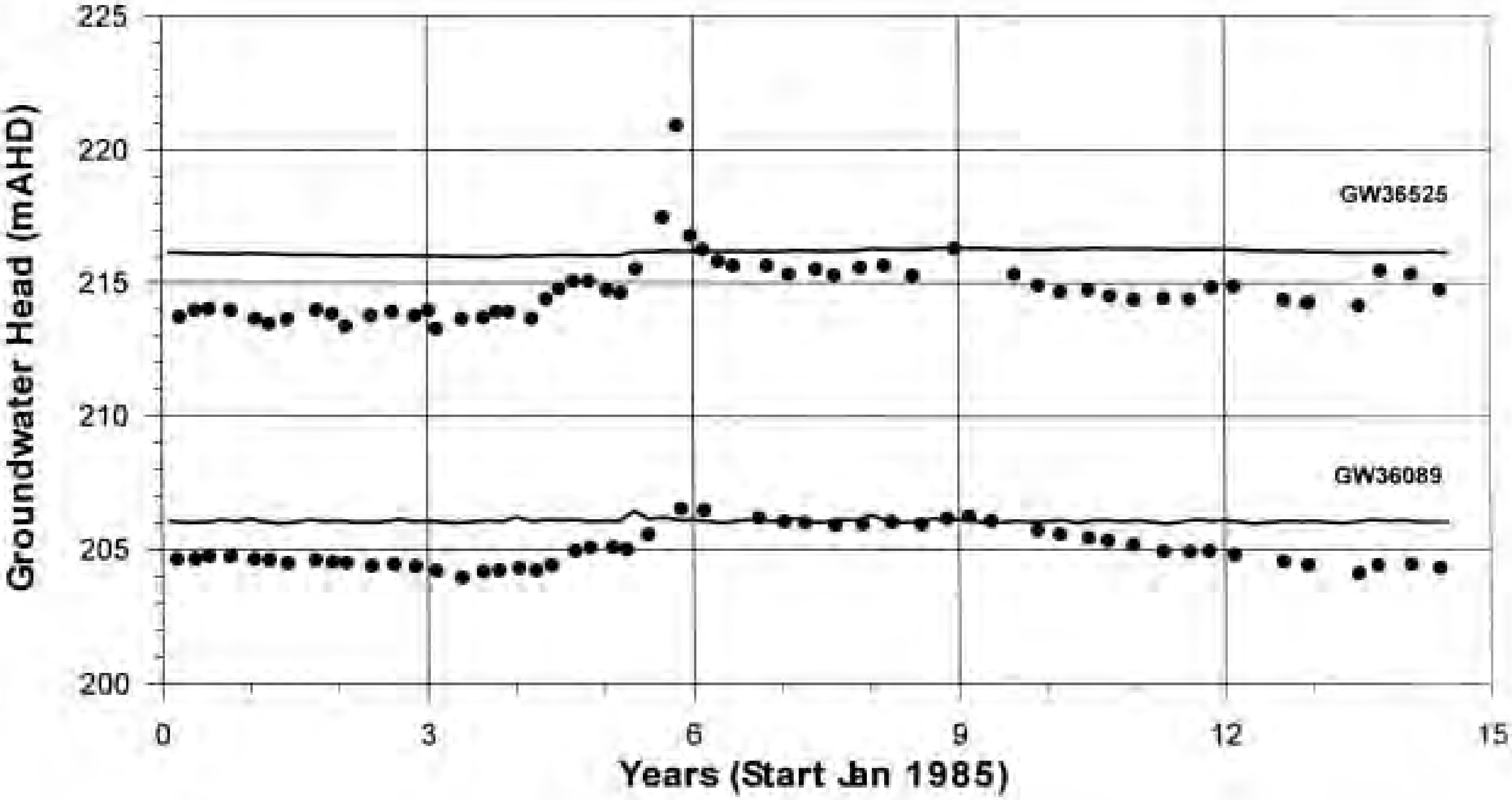
job no: G2000/3



● OBSERVED
— SIMULATED

Coffey Geosciences Pty Ltd [illegible]	Geotechnical | Resources | Environmental | Technical | Project Management	
Date: Aug 2000 Drawn: EEMW Approved:	BLACK RANGE MINERALS PTY LTD LACHLAN RIVER GROUNDWATER MODEL **OBSERVED AND SIMULATED GROUNDWATER LEVELS AT GW36526, GW36552, GW25151** MODEL 2	FIGURE E-20 job no. G2000/3

Coffey



Coffey Geosciences Pty Ltd | Geotechnical | Resources | Environmental | Technical | Project Management

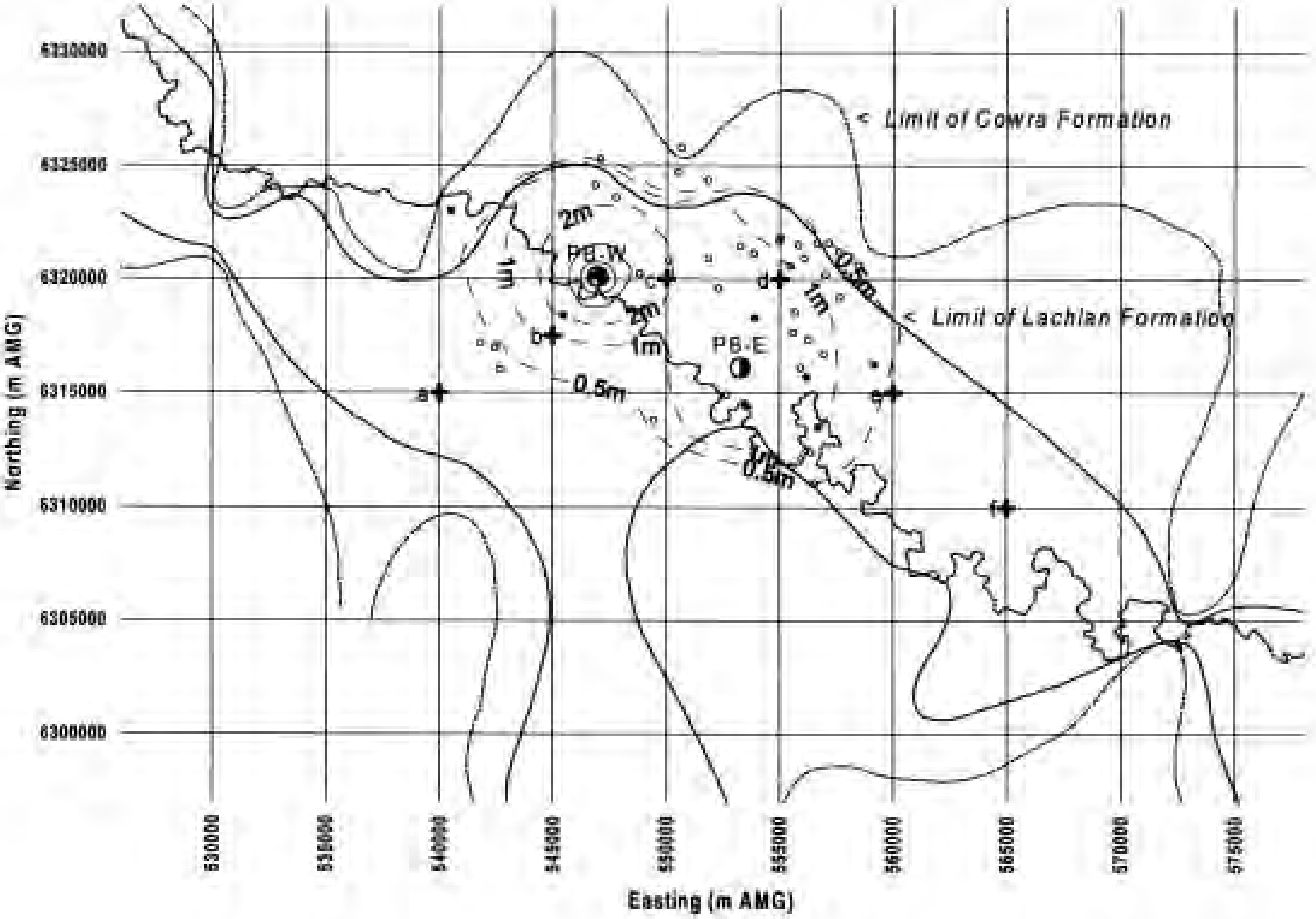
Date	Aug 2000
Drawn	EEMW
Approved	

BLACK RANGE MINERALS PTY LTD
LACHLAN RIVER GROUNDWATER MODEL

OBSERVED AND SIMULATED GROUNDWATER LEVELS
AT GW36525 AND GW36089
MODEL 2

FIGURE E-21

job no: G2000/3



—5m— Drawdown (m)

- ▪ Irrigation groundwater allocations
- ○ Stock and domestic bores
- ✚ Observation points for sensitivity simulations
- ◐ Production bores

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Geotechnical | Resources | Environmental | Technical | Project Management

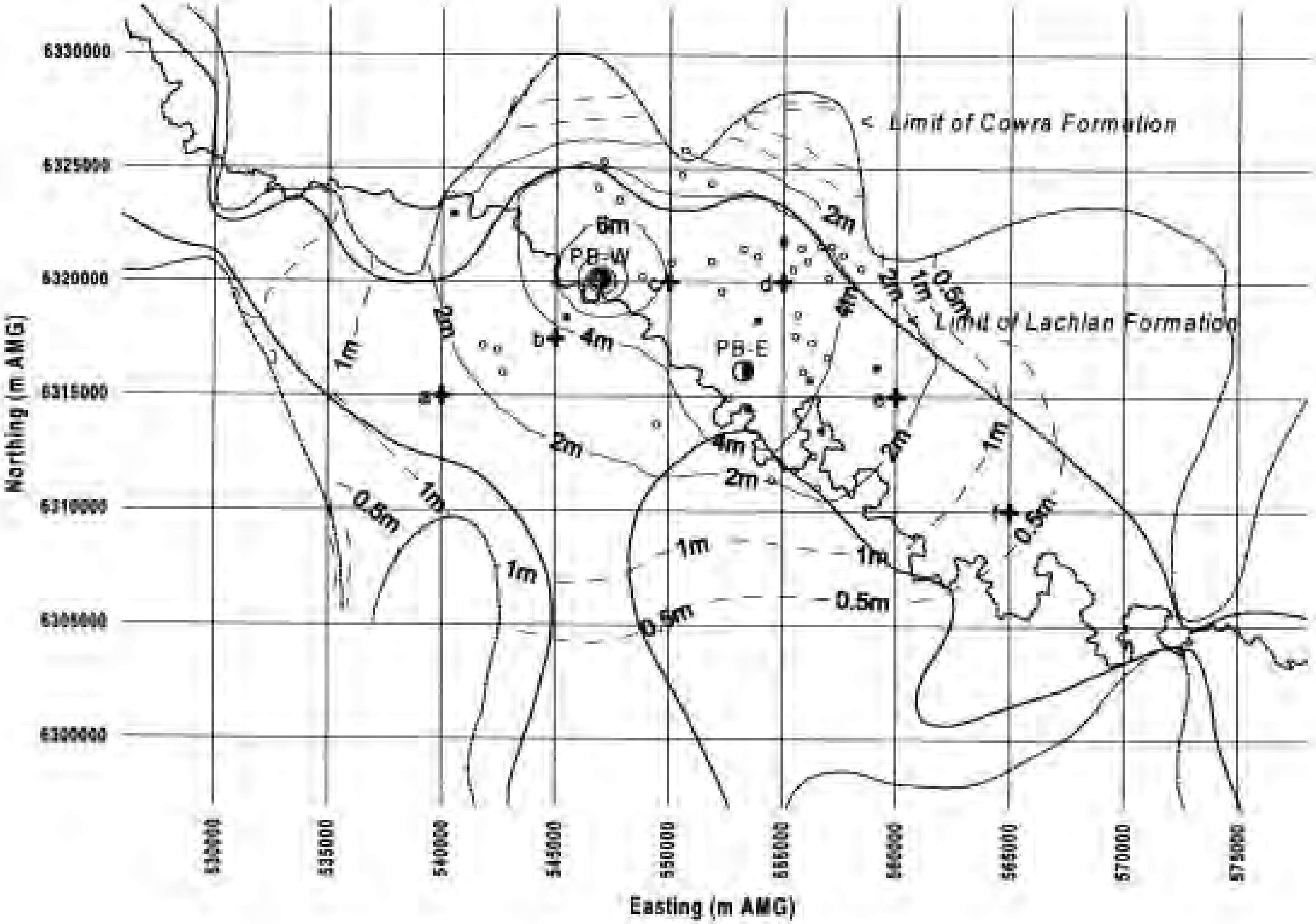
Drawn	JSR
Approved	
Date	Mar/2000
Scale	(as for grid)

BLACK RANGE MINERALS AUSTRALIA PTY LTD
LACHLAN RIVER GROUNDWATER MODEL

DRAWDOWN IN COWRA FORMATION
FOR 200 L/S, END OF YEAR 1
MODEL 1

FIGURE E-22

job no. G2800/3



-5m — Drawdown (m)
- ▪ Irrigation groundwater allocations
- ○ Stock and domestic bores
- ✚ Observation points for sensitivity simulations
- ◑ Production bores

Coffey Geosciences Pty Ltd

Geotechnical | Resources | Environmental | Technical | Project Management

Drawn	JSR
Approved	
Date	Mar/2000
Scale	(as for grid)

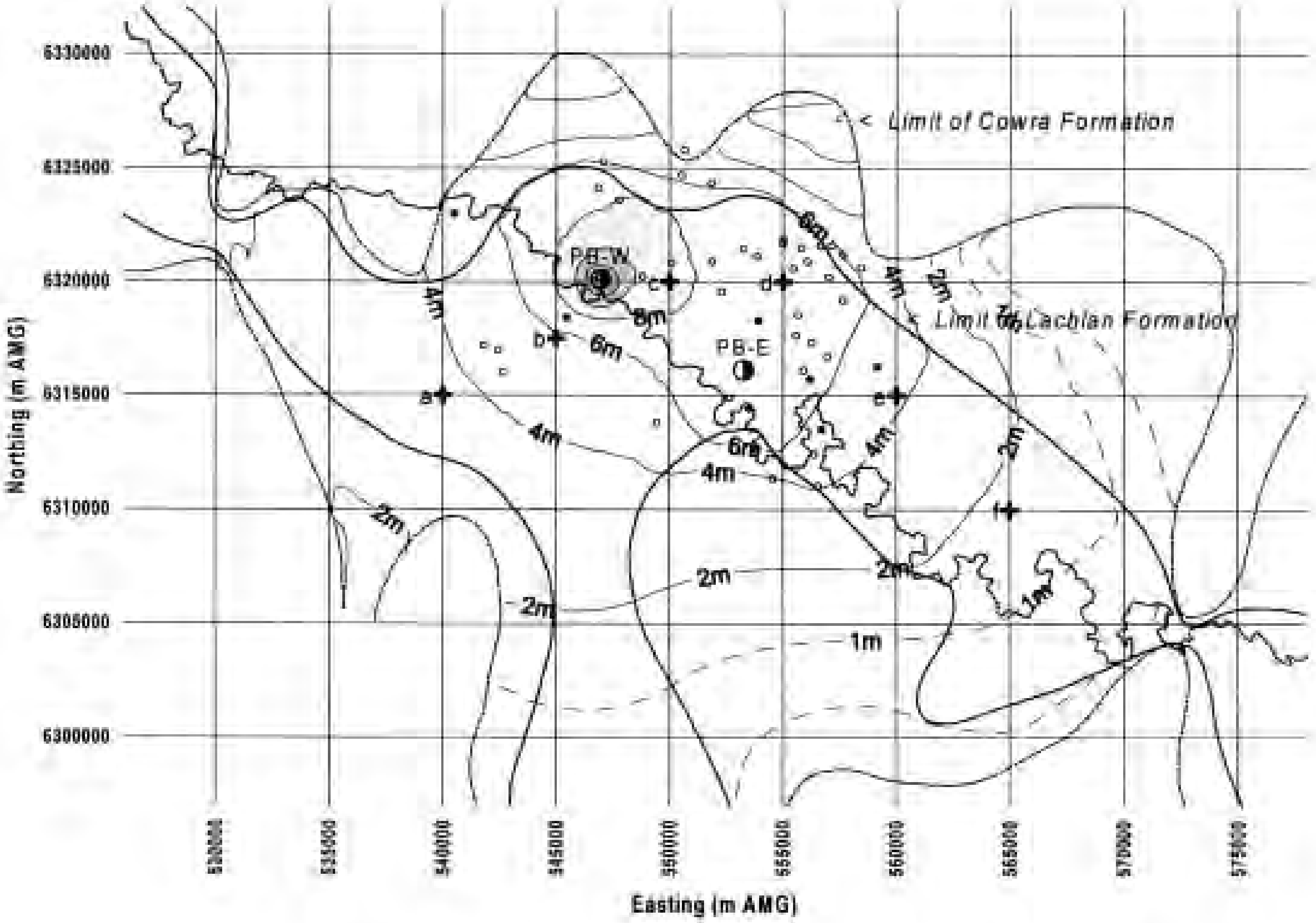
BLACK RANGE MINERALS AUSTRALIA PTY LTD
LACHLAN RIVER GROUNDWATER MODEL

DRAWDOWN IN COWRA FORMATION
FOR 200 L/S END OF YEAR 5
MODEL 1

FIGURE E-23

job no: G2000/3

Coffey



-5m- Drawdown (m)
▪ Irrigation groundwater allocations
▫ Stock and domestic bores
✚ Observation points for sensitivity simulations
◐ Production bores

Coffey Geosciences Pty Ltd
Geotechnical | Resources | Environmental | Technical | Project Management

Drawn	JSR
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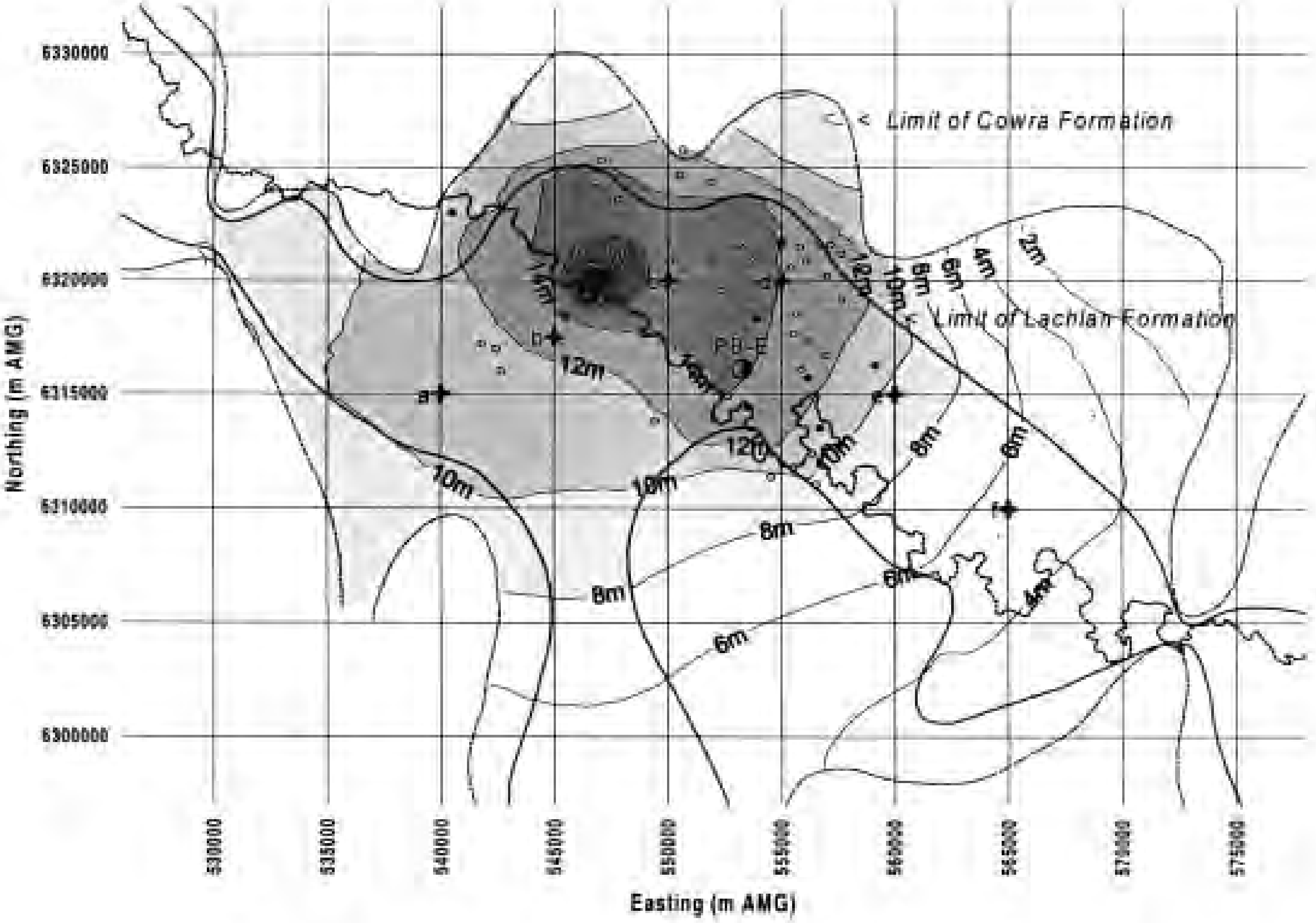
Date	Mar/2000
Scale	(as for grid)

BLACK RANGE MINERALS AUSTRALIA PTY LTD
LACHLAN RIVER GROUNDWATER MODEL
DRAWDOWN IN COWRA FORMATION
FOR 200 L/S END OF YEAR 10
MODEL 1

FIGURE E-24

job no: G2000/3



-5m- Drawdown (m)
- • Irrigation groundwater allocations
- ▫ Stock and domestic bores
- ✚ Observation points for sensitivity simulations
- ◐ Production bores

Coffey Geosciences Pty Ltd ACN 056 335 516

Geotechnical | Resources | Environmental | Technical | Project Management

Drawn	JSR
Approved	
Date	Mar/2000
Scale	(as for grid)

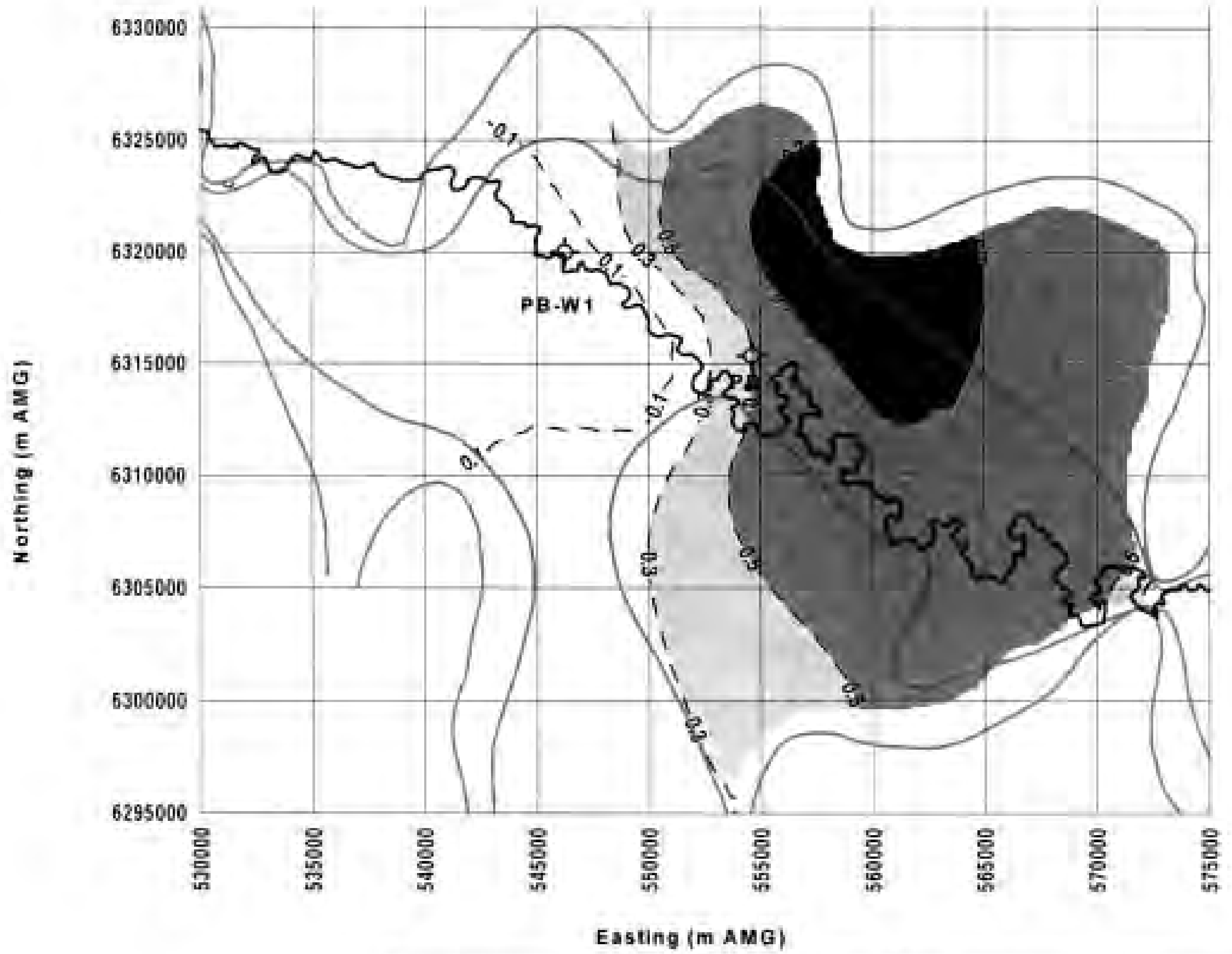
BLACK RANGE MINERALS AUSTRALIA PTY LTD
LACHLAN RIVER GROUNDWATER MODEL

DRAWDOWN IN COWRA FORMATION
FOR 200 L/S, END OF YEAR 30

MODEL 1

FIGURE E-25

job no: G2000/3



(Contours in metres)

Coffey Partners International Pty Ltd | Geotechnical | Resources | Environmental | Technical | Project Management

Drawn	MRG
Approved	
Date	Aug 2000
Scale	(as for grid)

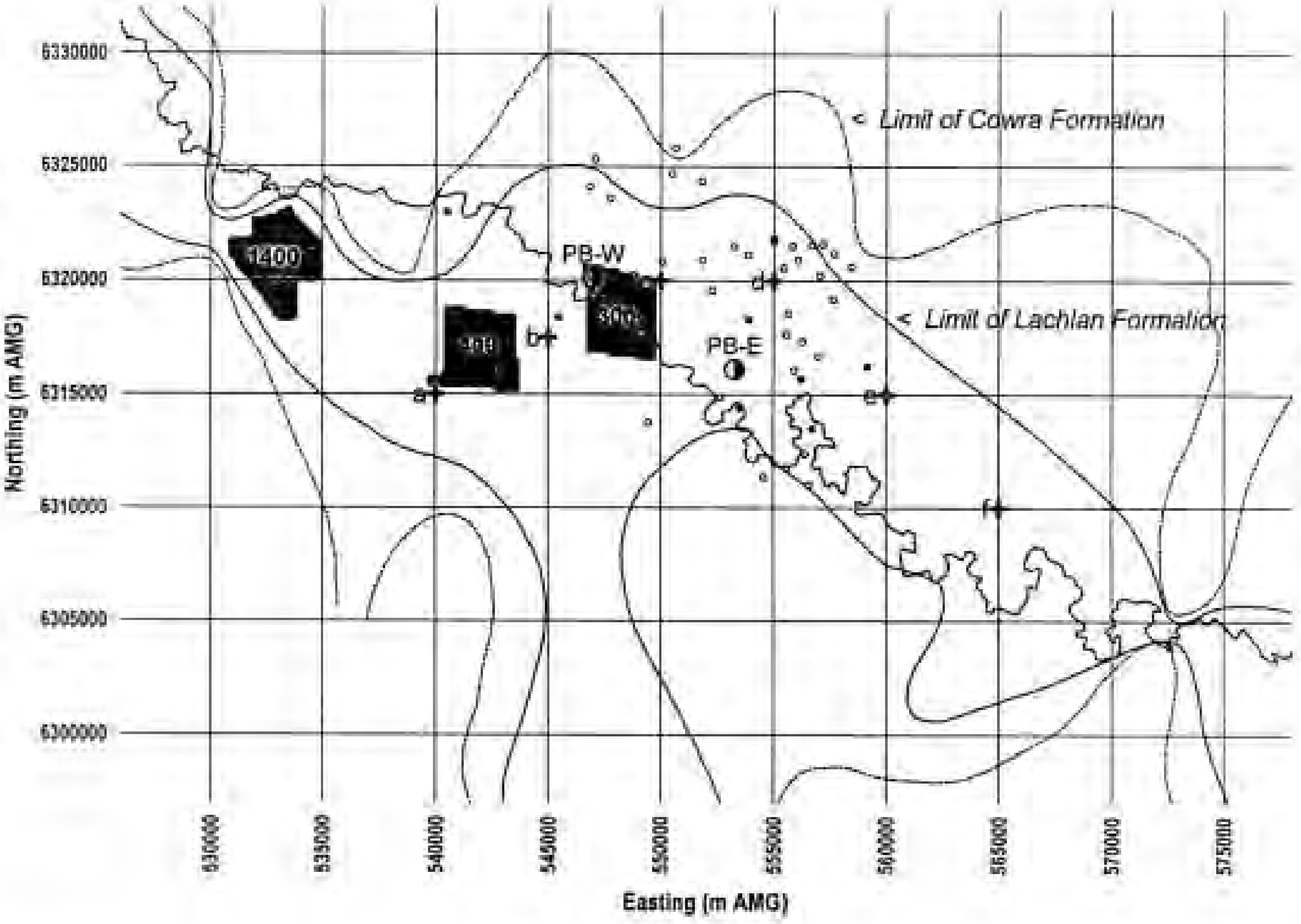
BLACK RANGE MINERALS PTY LTD
LACHLAN RIVER GROUNDWATER MODEL

MODEL 2
DRAWDOWN IN COWRA FORMATION
FOR 200 L/S, END OF YEAR 30

FIGURE E-26

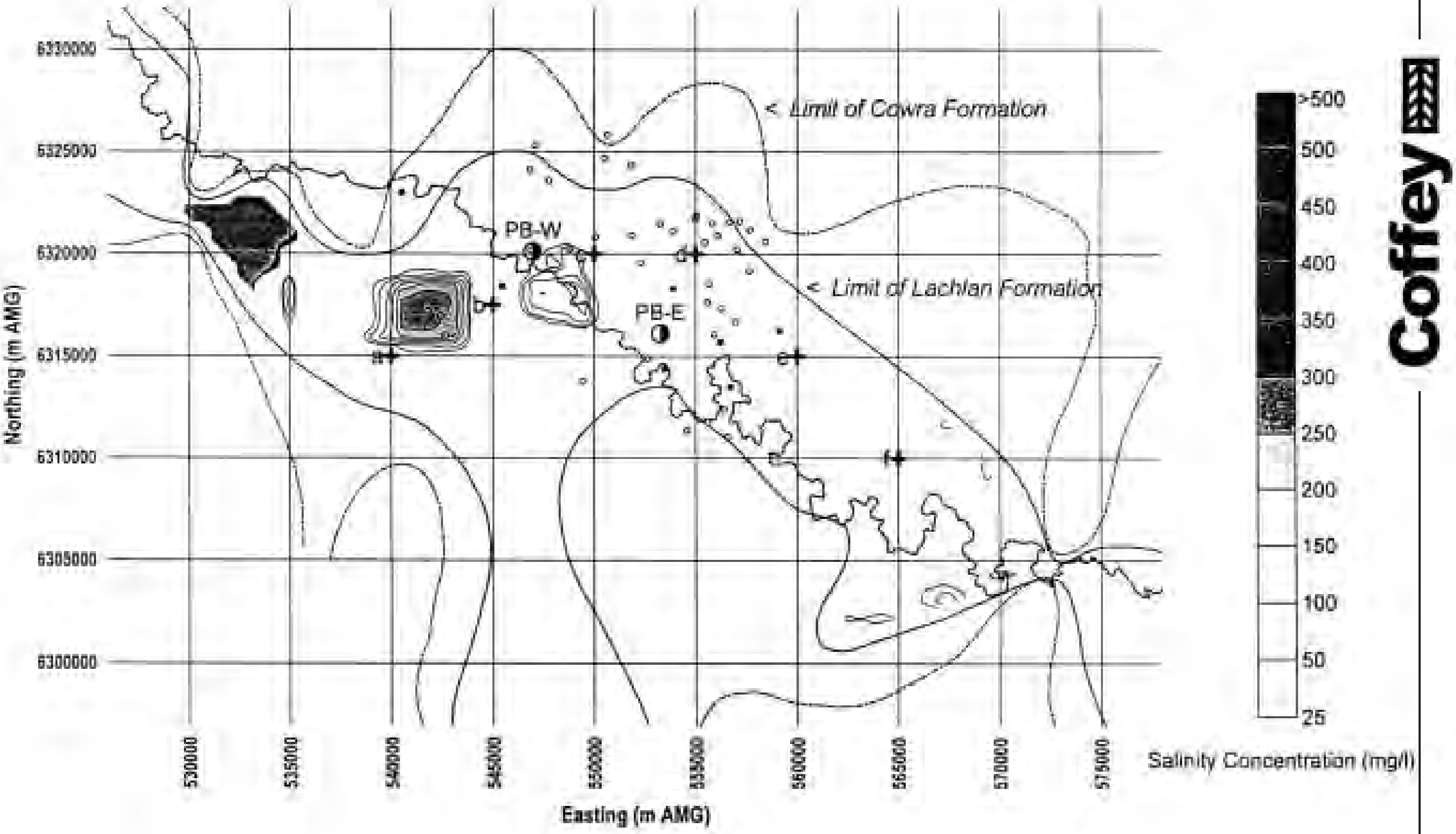
job no: G2000/3

Coffey



- • Irrigation groundwater allocations
- ▫ Stock and domestic bores
- ✚ Observation points for sensitivity simulations
- ◑ Production bores

Coffey Geosciences Pty Ltd ACN 056 336 516		Geotechnical | Resources | Environmental | Technical | Project Management	
Drawn	JSR	BLACK RANGE MINERALS AUSTRALIA PTY LTD LACHLAN RIVER GROUNDWATER MODEL INITIAL SALINITY CONCENTRATIONS (mg/l)	FIGURE E-27
Approved			
Date	Mar/2000		
Scale	(as for grid)		job no G2000/3



- • Irrigation groundwater allocations
- ∘ Stock and domestic bores
- ✚ Observation points for sensitivity simulations
- ◑ Production bores

Coffey Geosciences Pty Ltd ACN 056 335 516

Geotechnical | Resources | Environmental | Technical | Project Management

Drawn	JSR
Approved	
Date	Mar/2000
Scale	(as for grid)

BLACK RANGE MINERALS AUSTRALIA PTY LTD
LACHLAN RIVER GROUNDWATER MODEL
SIMULATED SALINITY CONTRATIONS FOR
THE LACHLAN FORMATION, YEAR 30

FIGURE E-28

job no: G2000/3

APPENDIX F
SYERSTON NICKEL COBALT PROJECT
ENVIRONMENTAL GEOCHEMICAL ASSESSMENT OF WASTE ROCK AND TAILINGS

PREPARED BY
RESOURCE STRATEGIES PTY LTD

OCTOBER 2000
Project No. BRM-01\3.12
Document No. APPENDIX F-E.DOC

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LIST OF TABLES

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LIST OF ATTACHMENTS

F1 INTRODUCTION

F1.1 BACKGROUND

Black Range Minerals (BRM) is proposing to develop the Syerston Nickel Cobalt Project (the Project) at Syerston, 45 km north-east of Condobolin and 80 km north-west of Parkes in the Central West of New South Wales. The Project would involve mining an average of 2 million tonnes per annum (tpa) of ore from a near surface lateritic deposit.

On-site processing facilities would be used to produce an average of approximately 20,000 tpa of metal or up to 42,000 tpa of mixed nickel-cobalt sulphide precipitate products. These products would be transported from the site, using a combination of existing road and rail networks, for sale to international markets.

An Environmental Impact Statement (EIS) for the proposed Project is required under the NSW *Environmental Planning and Assessment Act, 1979*. The Project has mineral resources adequate for a mine life of over thirty years. In accordance with regulatory requirements, the EIS assesses the potential environmental impacts of the Project for a term of 21 years.

F1.2 STRUCTURE OF THIS REPORT

This report is a supporting document to the EIS and presents the results of geochemical testwork conducted on samples of the waste rock and tailings to be produced by the Project.

Samples of waste rock from the proposed open pits and tailings from pilot plant testwork were taken by BRM for the purpose of geochemical testing and assessment of the acid forming potential of mine wastes. Environmental Geochemistry International (EGi) undertook the waste rock geochemical testwork and interpretation of results (EGi, 1999). Hazen Research Inc performed the tailings testwork; with EGi providing comment on the results (EGi, 2000).

In this report Resource Strategies provides a compilation of the available geochemical data and a summary of EGi's interpretation of the results.

F2 WASTE ROCK GEOCHEMISTRY

F2.1 BACKGROUND

The Syerston Project mining reserve is approximately 76.8 million tonnes (Mt) at 0.73% nickel and 0.13% cobalt. Mineralisation is largely confined to highly weathered geothitic clays and siliceous geothitic clays in deposits up to 30 m thick. These deposits typically occur at depths of 10 m to 60 m from the surface. In the first five to ten years of the Syerston Project, mining will be conducted from numerous relatively shallow open pits spread over the orebody. As these pits are expanded they will become connected so that by the end of the mine life (ie. in excess of some 30 years) one large open pit will have been formed.

Approximately 125 Mt of waste rock will be produced over 21 years. The quantity of waste rock produced annually will vary over the mine life but is expected to average some 6 Mt per annum. Waste rock is to be deposited in two emplacements located along the perimeter of the Project area (refer to Figure F1).

F2.2 WASTE ROCK SAMPLING

Nine waste rock samples were selected by BRM from the mining area based on pre-feasibility study mine designs. The samples were taken from six drillholes and included ironstone, interbedded clays, pisolitic gravels, goethite clays and smectite clays. The samples were taken at depths between 1 and 17 m below the surface. Table F1 summarises the drillhole and geological information for the samples. The locations of the drillholes are shown on Figure F1.

Table F1

Waste Rock Sample Descriptions

Pit Number	Drill Hole Number	Sample Interval	Geological Description	Mineralogy
1	SRC 431	1-5 m	Red maghemite rich pisolitic ironstone	Maghemite, clay haematite
		5-10 m	Brown haematite rich nodular ironstone	Maghemite, clay goethite
2	SRC 604	3-21 m	Orange cream and light red inter-bedded gritty clays with occasional quartz and maghaemite pisolith horizons	Smectite clays, quartz, maghemite, haematite
	SRC 733	2-8 m	Light orange brown goethite with minor clay, quartz and haematite and traces of magnesite	Goethite, smectite clay, quartz and haematite
4	SRC 642	2-10 m	Orange to brown inter-bedded gritty clays with horizons of quartz and pisolitic gravels	Smectite clays, quartz, maghemite, haematite and magnesite
		10-17 m	Orange to red brown pisolitic gravels and quartz gravels and lesser interstitial smectite clays, goethite and pyroxenite rock fragments	Smectite clays, quartz, maghemite, goethite, haematite and gibbsite
10	SRC 885	1-6 m	Decomposed maghemite pisoliths with interstitial smectite, quartz and goethite	Maghemite, goethite, smectite clays and minor quartz
	SRC 750	1-12 m	Cream, orange, white and red inter-bedded smectitic clays with bands of magnesite and minor pisolith and quartz gravel horizon	Smectite clays, magnesite, maghemite, goethite and lesser quartz
		12-16 m	Orange-brown pisolitic maghemite dust, haematite nodules with interstitial goethite and minor smectite clays	Smectite, haematite, maghemite and goethite

Source: Black Range Minerals (1999)

F2.3 SAMPLE PREPARATION AND TESTWORK PROGRAMME

Prior to testing, the samples were crushed and a split of approximately 300 grams (g) was pulverised. The following analyses were then carried out on the pulverised samples;

- pH and electrical conductivity (EC) determination on 2 parts solid to 1 part deionised water slurry;
- acid-base analysis (total sulphur and acid neutralising capacity (ANC)); and
- static net acid generation (NAG) tests.

The sulphur and ANC results were subsequently used to estimate the maximum potential acidity (MPA) and net acid producing potential (NAPP) of each sample.

Sydney Environmental & Soil Laboratory Pty Ltd, at the direction of EGi, carried out sample preparation and total sulphur assays. EGi carried out all other assays.

Further details of the testing procedures and an explanation of EGi's approach to evaluating mine waste rock geochemical data are presented in Attachment FA.

F2.4 ACID FORMING POTENTIAL

The acid forming characteristics of overburden samples taken from the mine site are presented in Table F2.

Table F2
Waste Rock Acid Forming Characteristics

Pit Number	Drill Hole Number	Depth Interval (m)	Paste pH	Paste EC (dS/m)	Total Sulphur (%S)	MPA*	ANC*	NAPP*	NAG*	Final NAG pH	Geochemical Classification
1	SRC 431	1-5	7.9	0.86	<0.01	<0.3	11	-11	0	7.1	NAF
		5-10	8.5	1.48	<0.01	<0.3	74	-74	0	9.7	NAF
2	SRC 604	3-21	8.3	1.12	<0.01	<0.3	131	-131	0	7.9	NAF
	SRC 733	2-8	8.4	0.77	<0.01	<0.3	18	-18	0	8.6	NAF
4	SRC 642	2-10	7.2	0.95	<0.01	<0.3	10	-10	0	6.5	NAF
		10-17	8.0	1.07	<0.01	<0.3	17	-17	0	8.0	NAF
10	SRC 885	1-6	8.0	0.83	<0.01	<0.3	50	-50	0	8.8	NAF
	SRC 750	1-12	8.1	1.09	<0.01	<0.3	67	-67	0	9.2	NAF
		12-16	8.2	1.12	<0.01	<0.3	17	-17	0	8.0	NAF

Source: Environmental Geochemistry International (1999)
NAF = Non Acid Forming
* Expressed as kg H_2SO_4/tonne

The results indicate that all of the samples were naturally alkaline (paste pH 7.2 to 8.5) and were slightly to moderately saline (paste EC 0.77 to 1.48 dS/m). The samples recorded low sulphur contents (<0.01 %S) and acid neutralising capacity (ANC) was moderate to high (10 to 131 kg H_2SO_4/t).

The NAPP results for the tested samples were all negative, indicating an excess availability of neutralising capacity. The NAG results confirmed no acid generation when the samples were reacted with hydrogen peroxide. Based on the results all nine samples were classified by EGi (1999) as non-acid forming (NAF).

F2.5 ELEMENT ENRICHMENT

Multi-element scans were performed on all nine waste rock samples and the results from these scans are presented in Table F3. These data indicate that Cr and Fe were significantly enriched in the samples (a not uncommon result in ultra-mafic parent rock environments).. The ranges in concentrations of Cr (515 – 13,700 ppm) and Fe (7.03 - 44.9 %) in the samples tested are up to 100 times higher than the average crustal abundance of these elements.

F3 TAILINGS GEOCHEMISTRY

F3.1 BACKGROUND

Tailings would be generated in the Syerston process plant and would be stored in a tailings storage facility (TSF) located to the south-east of the plant (Figure F1). The tailings would be pumped to the TSF as a slurry with a solids concentration of approximately 48%. A conventional sub-aerial spigot deposition system would be used to distribute the tailings across the beach of each TSF cell. This method of tailings deposition involves the progressive peripheral discharge of tailings slurry around the storage and results in thin layer beaching. It would also result in a decant pond of supernatant water forming around the centralised decant pumps.

Table F3
Waste Rock Sample Multi-element Composition

Drill Hole Number and Depth	Ag	Al	As	Ba	Bi	Ca	Cd	Ce	Co	Cr	Cu	Fe	Hg	Mg	Mn	Na	P	Pb	Sb	Se	Si	Zn
	ppm	*%*	*ppm*	*ppm*	*ppm*	*%*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*%*	*ppb*	*%*	*ppm*	*%*	*ppm*	*ppm*	*ppm*	*ppm*	*%*	*ppm*
SRC431 1-5m	<0.5	10.4	12	159	0.4	0.06	<1	14.6	58	6930	30	40.3	30	0.16	467	0.08	250	17	1.8	<1	5.1	54
SRC431 5-2m	<0.5	4.11	4	26	0.2	1.16	<1	37.2	362	6950	41	44.9	80	1.27	3130	0.11	250	6	0.4	<1	2.71	306
SRC604 3-21m	<0.5	7.13	14.5	190	0.3	0.94	<1	59	10	515	31	7.03	40	3.04	151	0.15	100	22	1.6	<1	27.4	20
SRC642 2-10m	<0.5	5.06	17	355	0.3	0.09	<1	37.8	22	1530	53	14.2	20	0.48	290	0.12	150	22	2.4	<1	29.5	41
SRC642 10-17m	<0.5	4.92	14	105	0.3	0.21	<1	25.2	130	13700	55	41.9	260	0.44	3130	0.08	400	17	1.4	1	6.09	108
SRC885 1-6m	<0.5	6.73	11.5	303	0.2	0.71	<1	30.6	92	4060	42	34.5	30	1.4	2120	0.08	200	11	1.6	<1	10	138
SRC733 2-8m	<0.5	4.8	3	269	0.1	0.36	<1	33	236	8530	81	37.7	100	0.71	4310	0.11	150	6	0.4	<1	9.52	226
SRC750 1-12m	0.5	6.69	9	219	0.2	2.55	<1	30.8	20	3200	64	16	30	2.56	412	0.13	100	14	1.4	<1	20.2	32
SRC750 12-16m	<0.5	6.79	6.5	19	0.2	0.13	<1	20.3	136	12500	48	39.4	130	0.6	1720	0.07	150	8	0.6	1	5.48	154

Source: Black Range Minerals (1999)

The initial starter embankments would be up to 11 m high, with the final height of the TSF cells predicted to be approximately 30 m at the end of their operational life. It is proposed to raise the outer embankments of the TSF cells using conventional upstream lifting techniques.

An underdrain system would be constructed at the inner toe of the embankment to intercept seepage and control the level of the phreatic surface within the TSF cells. Water collected in the underdrains would be piped to sumps outside the perimeter of the TSF embankment. These sumps would be dewatered to the TSF or to the evaporation ponds. The base of the TSF would be lined with a layer of compacted in-situ clay material.

F3.2 TESTWORK PROGRAMME

Geochemical tests conducted on the tailings sample included:

- selected multi-element scans on solids; and
- sequential batch leach testing.

Multi-element scans were performed to assess element enrichment within the solid sample. The sequential batch leach testing programme provides data for evaluating constituent solubility under different environmental conditions.

F3.3 TESTWORK RESULTS

A summary of EGi's discussion and interpretation of the tailings characterisation results (EGi, 2000) is presented below.

Multi-element Scans

The multi-element scans and geochemical abundance indices for the tailings sample are provided in Table F4. EGi concluded that Fe, Total S, Cr and Ni were significantly enriched in the tailings sample compared to their average crustal abundance. However, Cr concentrations were consistent with the ore and waste rock, while Ni was lower than the ore and similar to waste rock levels. The elevated sulphur content is likely to be associated with sulphates rather than sulphides due to process reactions.

Table F4
Multi-element Composition and Geochemical Abundance Indices for Tailings Solids

Element	Unit	Element Concentration in Tailings	* Average Crustal Abundance	# Geochemical Abundance Indices (GAI)
Major Elements				
Al	%	2.38%	8.2%	0
Ca	%	2.94%	4.0%	0
Fe	%	35.2%	4.1%	**3**
K	%	0.16%	2.1%	0
Mg	%	0.11%	2.3%	0
Na	%	0.12%	2.3%	0
S	%	4.10%	0.03%	**6**
Si	%	9.78%	27.7%	0

Table F4 (Continued)
Multi-element Composition and Geochemical Abundance Indices for Tailings Solids

Element	Unit	Element Concentration in Tailings	* Average Crustal Abundance	# Geochemical Abundance Indices (GAI)
Minor Elements				
Ag	mg/kg	0.002	0.07	0
As	mg/kg	11.4	1.5	2
Au	mg/kg	<0.002	0.0011	0
Ba	mg/kg	100	500	0
Bi	mg/kg	<50	0.048	-
Cd	mg/kg	<10	0.11	-
Cl	mg/kg	<100	130	0
Co	mg/kg	140	20	2
Cr	mg/kg	8270	100	**6**
Cu	mg/kg	10	50	0
Hg	mg/kg	0.20	0.05	1
Mn	mg/kg	4310	950	2
Mo	mg/kg	<50	1.5	-
Ni	mg/kg	1070	80	**3**
P	mg/kg	150	1000	0
Pb	mg/kg	<10	14	0
Sb	mg/kg	<50	0.2	-
Se	mg/kg	<1.4	0.05	-
Zn	mg/kg	<10	75	0

Source: Environmental Geochemistry International (2000)

* Bowen (1979) Environmental Chemistry of the Elements

\# GAI of 0 = not enriched > 6 = highly enriched

Sequential Batch-Leaching

The results of the sequential tailings batch-leaching tests conducted by Hazen Research Inc are presented in Table F5. In addition to the leachate assay data, Hazen Research Inc also provided data on the acid required to achieve the necessary pH conditions for each batch extraction.

F3.4 DISCUSSION OF RESULTS

Figure F2 shows the ‘equilibrium’ pH for increasing acid addition to the tailings as provided by the sequential batch-leaching tests. The results indicate that pH decreased to less than 6 after the addition of about 5 g H_2SO_4/kg to the tailings and decreased to less than pH 4 after about 10 g H_2SO_4/kg. This result suggests that the tailings have an effective buffering capacity of about 5 g H_2SO_4/kg.

Figure F3 is a box plot showing the solution concentrations for constituents in all batch extracts. This figure shows that calcium (Ca) and sulphate (SO_4) are the dominant constituents in solution and exhibit essentially identical concentrations in all extracts. Analysis of the data shows that the Ca to SO_4 molar ratio ranges from 0.92 to 1.0 indicating that gypsum solubility is effectively controlling the solubility of Ca and SO_4 in solution. This result indicates that the pore water and any potential seepage from these tailings would remain near equilibrium with gypsum.

Figure F3 also shows that the median Ni concentration exceeds 5 mg/L and the median Cr concentration exceeds 1 mg/L. All other metals are typically at very low concentrations and unlikely to be a concern from an environmental perspective at the batch extract natural pH.

Table F5
Sequential Batch Extraction Test Results for Tailings Solids

Parameter Extraction	Assay Unit	Natural pH				pH 5 Treatment				pH 4 Treatment				pH 3 Treatment			
		1	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
pH	-	7.59	7.61	7.76	7.78	7.68	7.63	7.43	6.73	7.26	6.96	6.70	4.97	5.71	4.51	3.74	3.31
Al	mg/L	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	1.4	0.8	8.1	11.1	8.0
Ca	mg/L	582	606	606	612	594	618	600	606	594	606	588	600	594	612	600	606
Cl	mg/L	7	5	5	5	5	5	5	5	6	5	5	5	5	5	5	5
Co	mg/L	0.02	0.02	0.02	0.02	0.02	0.03	0.12	0.54	0.11	0.87	0.89	0.48	1.86	1.01	0.62	0.35
Cr	mg/L	3.11	1.25	1.22	0.83	2.73	1.22	0.71	0.51	1.98	0.8	0.92	0.98	1.46	1.98	2.19	1.95
Cu	mg/L	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.05	0.05	0.06	0.05	0.03
Fe	mg/L	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.14
K	mg/L	0.14	0.14	0.12	0.07	0.05	0.12	0.11	0.14	0.48	0.36	0.52	0.72	0.52	0.95	0.96	1.03
Mg	mg/L	20.3	2.75	0.85	0.32	20.3	3.19	0.87	0.72	21.3	3.53	0.85	0.21	21.9	2.46	0.32	0.11
Mn	mg/L	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.57	0.02	1.16	3.51	2.93	4.55	5.33	3.63	2.16
Na	mg/L	2.18	2.15	2.02	1.94	1.93	2.02	1.91	2.02	3.14	2.69	2.79	2.77	2.07	2.97	3.00	2.84
Ni	mg/L	1.83	1.19	0.90	0.81	2.91	3.42	5.03	9.54	7.16	15.2	10.6	5.43	25.8	11.6	7.62	4.91
SO_4	mg/L	1490	1500	1450	1510	1520	1500	1510	1490	1550	1500	1480	1500	1540	1550	1550	1530
Zn	mg/L	0.02	0.02	0.02	0.02	0.02	<0.02	0.03	0.09	0.09	0.2	0.7	0.68	1.16	1.02	0.76	0.6

Source: Environmental Geochemistry International (2000)

Figure F4 shows the Ni and Cr concentrations in leach cycles at natural pH (pH 7.5 to 7.80). The initial Cr and Ni concentrations were about 3 and 2 mg/L, respectively and decreased to about 1 mg/L in subsequent extractions. Overall the amount of Cr and Ni leached from the tailings was about 60 mg/kg for Cr and 50 mg/kg for Ni. These results indicate that the long-term pore water chemistry is likely to approach about 1 mg/L for both Cr and Ni provided that the pH remains near neutral (EGi, 2000).

Figure F5 shows the effect of pH on the solubility of Ni and Cr in the tailings. The results demonstrate that Ni solubility is more sensitive to pH than Cr. At pH values between 6 and 7 the Ni concentration increased to more than 10 mg/L while the Cr concentration remained near 1 to 2 mg/L. The highest Ni concentration recorded was 25.8 mg/L for the first leach cycle of the pH 3 treatment which had final pH of 5.7.

Rehabilitation proposals for the TSF and evaporation ponds are likely to involve drying, capping and revegetation to support either grazing or woodlands.

F4 CONCLUSIONS

F4.1 ACID DRAINAGE RISK

The results of the geochemical investigations indicate that the risk of developing acid drainage at Syerston is very low to nil. The materials excavated by the mining operations would be mined from relatively shallow depths and are highly weathered. As a consequence acid drainage is not expected by EGi to occur in the waste rock emplacements. Acid drainage should not occur in the tailings storage facility over the life of the mine (ie. all tailings would be neutralised in the process plant and would be discharged at a pH of approximately 7 to 7.5). However, an ongoing periodic acid-base and NAG testing program during operations is recommended to confirm the long-term non acid forming behaviour of tailings.

F4.2 ELEMENT ENRICHMENT AND LEACHING

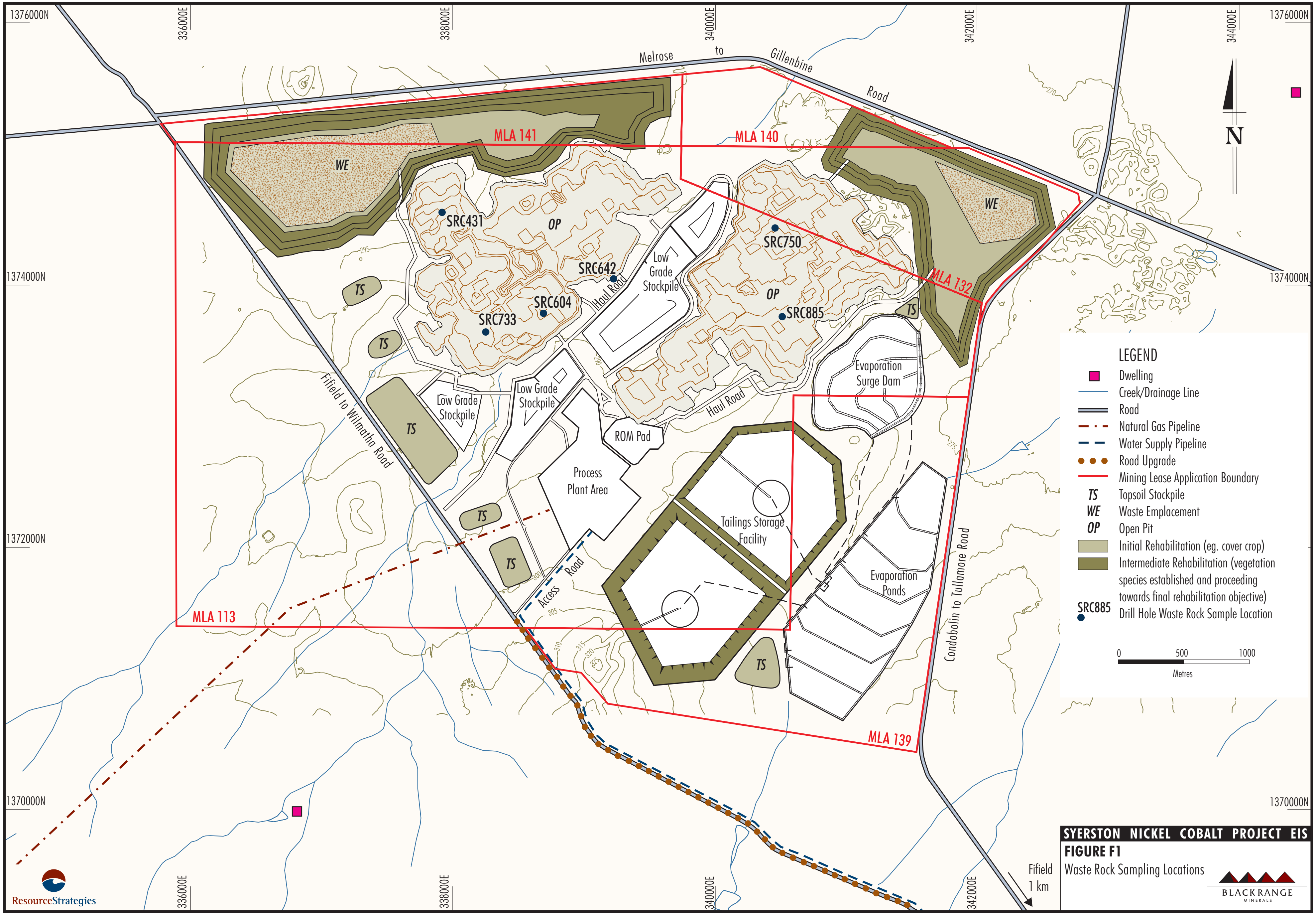
Cr, Fe and Ni are expected to be significantly enriched in the waste rock and tailings relative to average crustal abundances. The significance of these enrichments depends on element solubility and leaching behaviour. It is expected that mine water will maintain a near neutral pH into the long term, therefore the risk of increased solubility of these elements is expected to be low. During operation of the tailings storage facility inputs of acid water could have a significant affect on Ni solubility. It is recommended that plant design ensures that tailings report to the TSF at a pH greater than 7 with an operational target of 7.5. In the long-term, it is expected that mine water will maintain a near neutral pH, therefore the risk of increased solubility of these elements is expected to be low.

F5 REFERENCES

EGi (1999) *Assessment of Waste Rock Acid Forming Characteristics*. Fax report by Environmental Geochemistry International for Golder Associates.

EGi (2000) *Review of Tailings Geochemical Results*. Memo prepared by Environmental Geochemistry International for Black Range Minerals.

FIGURES



SYERSTON NICKEL COBALT PROJECT EIS

FIGURE F1

Waste Rock Sampling Locations

BRM-98-01-Waste GeoChem_001E

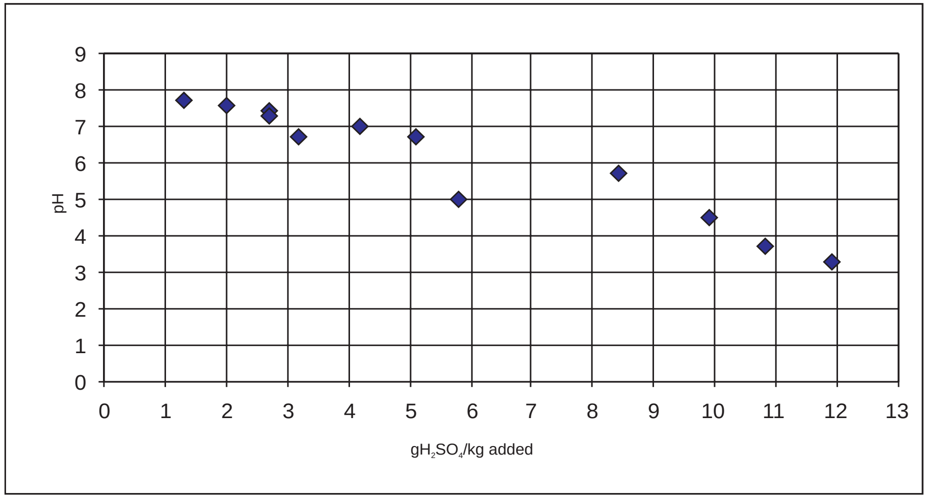


Figure F2: pH buffer curve for Syerston nickel tailings

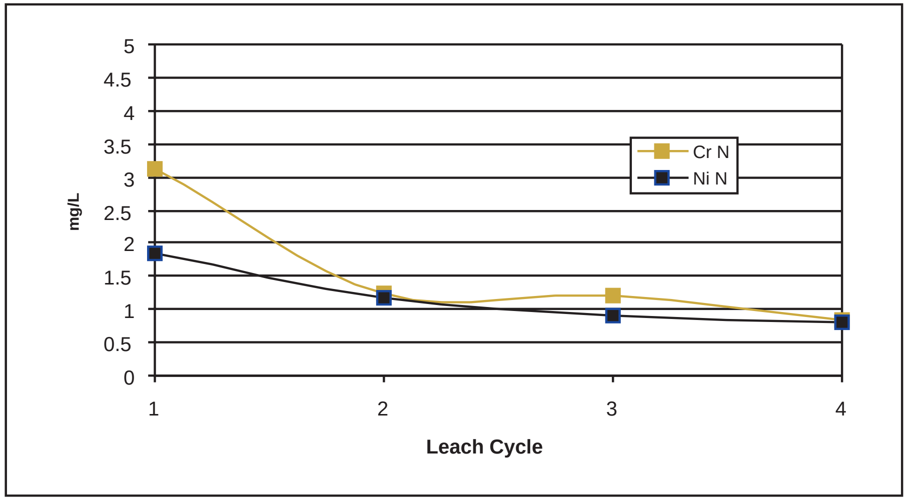


Figure F4: Ni and Cr concentrations in leach cycles at natural pH (pH 7.5 to 7.80)

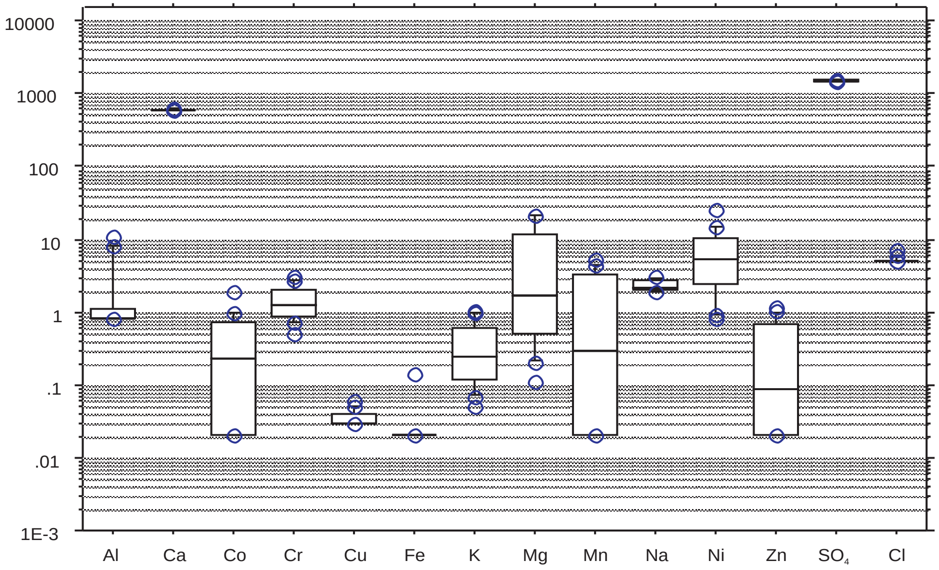


Figure F3: Box plot showing solution concentrations in batch extracts

NB: Box indicates 25th, 50th and 75th percentiles; extended crossed lines indicate the 10th and 90th percentiles; data points outside this range are also shown

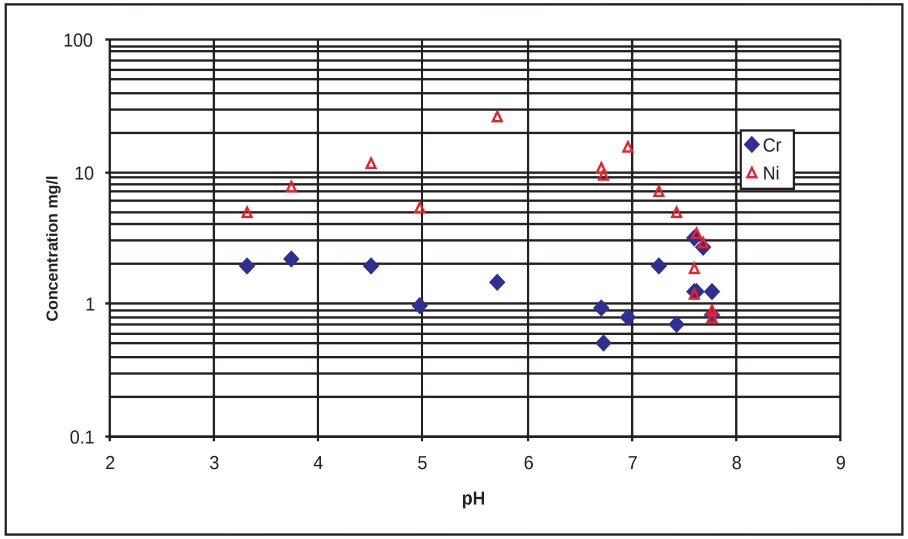


Figure F5: Ni and Cr concentrations as a function of pH in batch extracts

ResourceStrategies

Source: Environmental Geochemistry International, 2000

SYERSTON NICKEL COBALT PROJECT EIS

FIGURE F2, F3, F4 and F5

Tailings Analyses

BLACK RANGE MINERALS

ATTACHMENT FA

ASSESSMENT OF WASTE ROCK ACID FORMING CHARACTERISTICS

(After: Environmental Geochemistry International, 1999)

Evaluation of Mine Waste Geochemical Data

Acid Generation and Prediction

Acid generation is caused by the exposure of sulphide minerals, most commonly pyrite (FeS_2), to atmospheric oxygen and water. Sulphur assay results are used to calculate the maximum acid that could be generated by the sample by either directly determining the pyritic S content or assuming that all sulphur not present as sulphate occurs as pyrite. Pyrite reacts under oxidising conditions to generate acid according to the following overall reaction:

$$FeS_2 + 15/4\ O_2 + 7/2\ H_2O \text{ ---> } Fe(OH)_3 + 2\ H_2SO_4$$

According to this reaction, the maximum potential acidity (MPA) of a sample containing 1 %S as pyrite would be 30.6 kg H_2SO_4/t.

The chemical components of the acid generation process consist of the above sulphide oxidation reaction and acid neutralisation which is mainly provided by inherent carbonates and to a lesser extent silicate materials. The amount and rate of acid generation is determined by the interaction and overall balance of the acid generation and neutralisation components.

Net Acid Producing Potential

The net acid producing potential (NAPP) is used as an indicator of materials that may be of concern with respect to acid generation. The NAPP calculation represents the balance between the maximum potential acidity (MPA) of a sample, which is derived from the sulphide sulphur content, and the acid neutralising capacity (ANC) of the material, which is determined experimentally. By convention, the NAPP result is expressed in units of kg H_2SO_4/t sample. If the capacity of the solids to neutralise acid (ANC) exceeds their capacity to generate acid (MPA), then the NAPP of the material is negative. Conversely, if the MPA exceeds the ANC, the NAPP of the material is positive. A NAPP assessment involves a series of analytical tests that include:

Determination of pH and EC

pH and EC measured on 1:2 w/w water extract. This gives an indication of the inherent acidity and salinity of the waste material when initially exposed in a waste emplacement area.

Total sulphur content and maximum potential acidity (MPA)

Total sulphur content is determined by the Leco high temperature combustion method. The total content is then used to calculate the MPA, which is based on the assumption that all the sulphur occurs as reactive pyrite. A more accurate estimate of the MPA can be made by determining pyritic sulphur and other sulphur forms directly.

Acid neutralising capacity (ANC)

By addition of acid to a known weight of sample, then titration with NaOH to determine the amount of residual acid. The ANC measures the capacity of a sample to react with and neutralise acid. The ANC can be further evaluated by slow acidimetric titration to a set end-point and then calculation of the amount of acid consumed and evaluation of the resultant titration curve.

Net acid producing potential (NAPP)

Calculated from the MPA and ANC results. The NAPP represents the balance between a sample's inherent capacities to generate and neutralise acid. If the MPA is greater than the ANC then the NAPP is positive. If the MPA is less than the ANC then the sample then the NAPP is negative.

Acid-Base Characteristic Curve

The acid-base characteristic curve (ABCC) test involves the slow titration of a sample/water suspension with HCl to pH 3. This test is used to determine how effective the ANC of a sample is at neutralising sulphide generated acid.

Net Acid Generation

The net acid generation (NAG) test involves the addition of hydrogen peroxide to a sample of mine rock or process residue to oxidise reactive sulphide, then measurement of pH and titration of any net acidity produced by the acid generation and neutralisation reactions occurring in the sample. A significant NAG result (*i.e.* final NAGpH < 4.5) confirms that the sample is potentially acid forming and the test provides a direct measure of the net amount of acid remaining in the sample after all acid generating and acid neutralising reactions have taken place. A NAGpH <4.5 indicates that the sample is non-acid generating.

The NAG test provides a direct assessment of the potential for a material to produce acid after a period of exposure and weathering and is used to refine the results of the theoretical NAPP predictions. Variations of the standard static NAG test include a sequential static NAG test and field NAG test. The NAG test can be used as a stand alone test but it is recommended that this only be considered after site specific calibration work is carried out. The NAG test kinetics can also be monitored during the reaction and the acquired data can be used to provide an indication of the sulphide reactivity and likely reaction kinetics in the field.

Assessment of Element Enrichment and Solubility

Multi-element scans are carried out to identify any elements that are present in a material at concentrations that may be of environmental concern with respect to surface water quality and revegetation. The samples are generally analysed for the following elements:

Major elements: Al, Ca, Fe, K, Mg, Na, Si, S
Trace elements: Ag, As, B, Ba, Be, Bi, Cd, Ce, Co, Cr, Cu, F, Hg, Mn, Mo, Ni, P, Pb, Sb, Se, Sn, Sr, Tl, V, W, Zn

The assay result for each element is compared to the average crustal abundance for that element (Bowen, 1979[1]) to provide a measure of the extent of element enrichment.

The extent of enrichment is reported as the Geochemical Abundance Index (GAI) which relates the actual concentration with the crustal abundance on a log 2 scale. The GAI is expressed in 7 integer increments (*i*.e. 0 through to 6), where a GAI of 0 indicates the element is present at a concentration similar to, or less than, average crustal abundance; and a GAI of 6 indicates approximately a 100-fold, or greater, enrichment above average crustal abundance. As a general rule, a GAI of 3 or greater signifies enrichment that warrants further examination.

It should be noted that heavy metal enrichment of waste material is a common feature at mine sites and the GAI is simply a convenient measure with which to assess elements that may need further investigation or monitoring.

A significant GAI (i.e. GAI <3), does not mean that an enriched element will necessarily be a concern for revegetation, drainage water quality, or public health. Similarly, because an element is not significantly enriched does not mean it will never be a concern, because under some conditions (e.g. low pH) the geochemical behaviour of common environmentally important elements such as Al and Fe increase significantly. Water extracts are used to determine the immediate element solubilities under the existing sample pH conditions of the sample.

For the assessment of element enrichment and solubility the following tests are carried out:

Multi-element composition of solids

Multi-element composition of solid samples determined using a combination of ICP-mass spectroscopy (ICP-MS), ICP-optical emission spectroscopy (OES), and atomic absorption spectrometry (AAS).

Multi-element composition of water extracts (1:2 sample:deionised water)

Multi-element composition of water extracts from solid samples determined using a combination of ICP-mass spectroscopy (ICP-MS), ICP-optical emission spectroscopy (OES), and atomic absorption spectrometry (AAS).

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[1] Bowen, H.J.M. (1979) Environmental Chemistry of the Elements. Academic Press, New York, p 36-37.