Jul '92

SYNTHETIC RUTILE PLANT EXPANSION
CAPEL
WESTERN AUSTRALIA

CONSULTATIVE ENVIRONMENTAL REVIEW

JULY 1992

Westralian Sands Limited

SUBMISSIONS ON THE PROPOSAL

Invitation

The Environmental Protection Authority (EPA) invites people to make a submission on this proposal.

The Consultative Environmental Review (CER) has been prepared in accordance with the Government of Western Australia (Government) procedures. The report will be available for comment until Tuesday, 25 August 1992.

Comments from Government agencies and from the public will assist the EPA to prepare an Assessment Report in which it will make a recommendation to Government.

Following receipt of comments from Government agencies and the public, the EPA will discuss these comments with the proponent and may ask for further information. The EPA will then prepare an assessment report with recommendations to Government, taking into account issues raised in the public submissions.

Why write a submission?

A submission is a way to provide information, express your opinion and put forward your suggested course of action including any alternative approach. It is helpful if you indicate any suggestions you may have to improve the proposal.

All submissions received will be acknowledged.

Developing a submission

You may agree or disagree, or comment on, the general issues discussed in the CER or with specific proposals. It helps if you can give reasons for your conclusions, supported by relevant data.

You may make an important contribution by suggesting ways to make the proposal environmentally more acceptable.

When making comments on specific proposals in the CER:

- clearly state your point of view;
- indicate the source of your information or argument if this is applicable; and
- suggest recommendations, safeguards or alternatives.

Points to keep in mind

By keeping the following points in mind, you will make it easier for your submission to be analysed.

Attempt to list points so that the issues raised are clear. A summary of your submission is helpful. Refer each point to the appropriate section, chapter or recommendation in the CER. If you discuss different sections of the CER keep them distinct and separate, so there is no confusion as to which section you are considering.

Attach any factual information you wish to provide and give details of the source. Make sure your information is correct.

Please indicate whether your submission can be quoted, in part or in full by the EPA in its Assessment Report.

REMEMBER TO INCLUDE YOUR NAME, ADDRESS AND THE DATE.

THE CLOSING DATE FOR SUBMISSIONS - 25 AUGUST 1992.

SUBMISSIONS SHOULD BE ADDRESSED TO:

The Chairman
Environmental Protection Authority
Westralia Square
PERTH WA 6000

Attention: Mr Geoff Fulford.

SUMMARY

SUMMARY

INTRODUCTION

Westralian Sands Limited, a mineral sand mining and processing company, is proposing to expand its synthetic rutile plant at North Capel, Western Australia. Nominal capacity will be increased from 100,000 to 230,000 tonnes per annum.

Approximately 90 per cent of Westralian Sands' titaniferous minerals are used in the production of titanium dioxide pigment. Restructuring of the pigment industry has meant a preference for newer chloride technology over the older sulphate process. The chloride process uses high TiO_2 feed stocks such as synthetic rutile. Synthetic rutile stands out as a major growth area for titaniferous minerals.

The existing plant, commissioned in December 1986, is located 4.5 kilometres north of the town of Capel. An expansion of the plant on the existing site, utilising developed infrastructure is logical. The experience of the past five years of operation has shown that environmental and social impacts can be successfully managed.

THE PROCESS

The synthetic rutile process utilised in the existing plant is the traditional Becher process. The expansion will use either the Becher process or an alternative process, currently the subject of a research and development programme at Westralian Sands. The alternative technology applies to the stage of the process that removes iron and manganese from the reduced ilmenite. A pressure oxidation process replaces aeration, acid leaching and significantly reduces the need for neutralisation.

ENVIRONMENTAL IMPACTS AND MANAGEMENT

The relevant environmental issues associated with the project and discussed in the CER are as follows:

- **Raw Materials:**
  Westralian Sands will not increase mine capacity but will purchase ilmenite from other mining companies as required and will divert ilmenite, currently exported, for further processing.

- **Transport:**
  Coal consumption will double. It will be transported from Collie by covered road trucks on a 5 day a week, 21 loads per day basis.

Ilmenite and synthetic rutile constitute the major material movements. The expansion will mean ilmenite that is currently transported and exported will be upgraded to synthetic rutile. Combined ilmenite and synthetic rutile truck movements on the Bussell Highway will be very similar to the existing numbers.

- **Liquid and Solid Waste Management:**
  The expanded plant will produce one extra source of liquid effluent - neutralised liquor from acid leach or the new process. This will join the existing effluent streams of scrubber liquor and neutralised liquor from acid leach. The water quality discharged from site will meet guidelines for drinking water quality for all health related inorganic chemicals.

  Neutralised effluent solids are recovered from settlement dams. The material is very fine and research has shown it to be a potent absorber of nutrients. Potential uses are under investigation.

  Iron oxide wastes have a small market as a fertiliser additive, water treatment chemical or a cement additive. The remainder is returned to a mine pit.

  The North Capel mine pit, adjacent to the plant, is used as the disposal site for solid wastes that can't be used. The ground water is monitored by piezometers to determine leaching through the compacted solids. No contamination has been detected as a result of existing disposal practice.

- **Noise:**
  Predictive noise modelling indicates the proposed plant will generate approximately 10 dBA less than the existing plant. No additive effect is expected. During calm conditions resultant levels of the combined plant will be 40-43 dBA at the nearest residential locations. No tonal or other annoying characteristics exist in the noise.

  Certain weather conditions will result in higher levels. A monitoring and modification programme is underway to reduce the impact of the existing plant. The programme will cover the expanded plant after commissioning to ensure that acceptable neighbourhood noise levels are achieved within two years.

- **Ground Water Consumption:**
  Water is drawn from deep aquifers of the Yarragadee Formation. The plant expansion will require up to 2 million m^3 per annum of water in addition to the 2.7 million m^3

per annum currently extracted. A study commissioned to investigate this increase in aquifer draw has indicated this can be adequately met by the aquifer.

Process changes, including dry scrubbing of waste gas streams, will result in more efficient use of water resources.

- **Ground Water Quality:**
  A network of piezometers monitor ground water quality around the plant. Site hygiene, appropriate containment of materials with the potential to contaminate ground water and adequate storm water drainage are integral parts of managing ground water quality.

- **Air Quality:**
  Air quality is impacted by the generation of sulphur dioxide, particulate (dust) and under certain conditions, unpleasant odours.

  Plume dispersion modelling has been carried out using the AUSPLUME model and CSIRO's Lagrangian model. The sulphur dioxide ground level concentrations will comply with the Draft Environmental Protection Policy for Sulphur Dioxide and Dust in the Kwinana Region, December 1989.

  The waste gas stream will be treated by:
  1. Dust settling chamber to remove larger dust particles.
  2. An afterburning chamber to convert hydrogen sulphide to sulphur dioxide.
  3. An electrostatic precipitator to remove fine particulate.

  An existing dust management strategy will be further developed to ensure dust loadings in the air are minimised. The levels will comply with the Draft Environmental Protection Policy for Sulphur Dioxide and Dust in the Kwinana Region, December 1989.

  Strong odours, which have been an occasional problem, are being successfully managed by
  1. water treatment to remove bacteria and algae and
  2. process changes to ensure complete combustion of coal and hydrogen sulphide.

- **Socio-economic Issues:**
  The proposed expansion will employ up to 200 people during the two year construction phase. Temporary accommodation in the Bunbury Capel area will be

used to house the construction workforce. Should a construction camp be decided upon, a management plan will be drawn up in consultation with the Shire of Capel and to the satisfaction of the EPA.

It is anticipated that the permanent workforce of 50 will be recruited locally. Additional demand for accommodation will be minimal.

Wages associated with the construction and operation of the project will add considerably to the economic well-being of the Shire and region. Significant flow-on income effects are expected to result from this injection into the local economy.

The expansion will contribute approximately $60M ($1992) per year to the country's export income.

MANAGEMENT COMMITMENTS AND MONITORING

A comprehensive environmental monitoring programme has been designed to provide the necessary data to allow confirmation of predicted environmental impacts and ensure compliance with legislative controls and standards.

Westralian Sands has made 63 commitments relating to the management of the plant and monitoring of its effects on the environment. The commitments are auditable and include details for reporting the results of the environmental monitoring programme.

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ABBREVIATIONS

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Guidelines for Consultative Environmental Review.

APPENDIX 2
How to make a Submission.

APPENDIX 3
Groundwater Resource Evaluation of the Yarragadee Formation to meet the Process Water Supply Demands of the Proposed Second Synthetic Rutile Plant at Capel, Western Australia.

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Air Dispersion Modelling Study of Westralian Sands North Capel Synthetic Rutile Plant – Dames & Moore.

1. INTRODUCTION

1.1 THE PROPONENT

Westralian Sands Limited is a mineral sands mining and processing company based at Capel, Western Australia. The company was first incorporated in 1954. Ownership of the company is currently:–

• Tioxide Australia Pty Ltd (TAPL)	44.7%
• Public investors on the Australian Stock Exchange (representing 10,314 holders)	37.0%
• Ishihara Sangyo Kaisha Ltd (ISK)	18.3%

Tioxide Australia is a wholly owned subsidiary of Tioxide Group Ltd that is, in turn, a wholly owned subsidiary of ICI. Tioxide Australia operates a titanium dioxide pigment plant at Burnie, Tasmania.

Ishihara Sangyo is a publicly owned Japanese company which produces titanium dioxide, magnetic iron oxide, synthetic rutile, fertiliser, agricultural chemicals and mineral sands.

Westralian Sands operates three mineral sand mines and a synthetic rutile plant in the Capel area and a diatomite mine at Barraba, New South Wales.

1.2 BACKGROUND

Westralian Sands is proposing an expansion of its North Capel synthetic rutile plant. Nominal capacity will be increased from 100,000 to 230,000 tonnes per annum.

The company is one of the world's major producers of titanium bearing minerals used for pigments and high technology products.

Approximately 90 percent of Westralian Sands' titaniferous minerals are used in titanium dioxide pigment production.

Sulphate pigment plants use ilmenite (52–60 percent TiO_2) as feedstock to produce TiO_2 via the sulphate process. A major by–product is an acidic effluent high in iron which is produced in large volumes.

The more modern chloride process produces high quality pigment by chlorinating rutile, synthetic rutile (85–95 percent TiO_2) or titanium slag. Waste by–products are significantly reduced.

In future, most new pigment plants will use chloride route technology. The trend to producing pigment by this route has increased demand for feedstocks which have a high titanium dioxide content, that is rutile, synthetic rutile and titanium slag. Figure 1.1 shows the trend in pigment production using historical and forecast data. The higher grade chloride feedstock is also six times the value of ilmenite. Both price and forecast demand provide an incentive to produce more upgraded material.

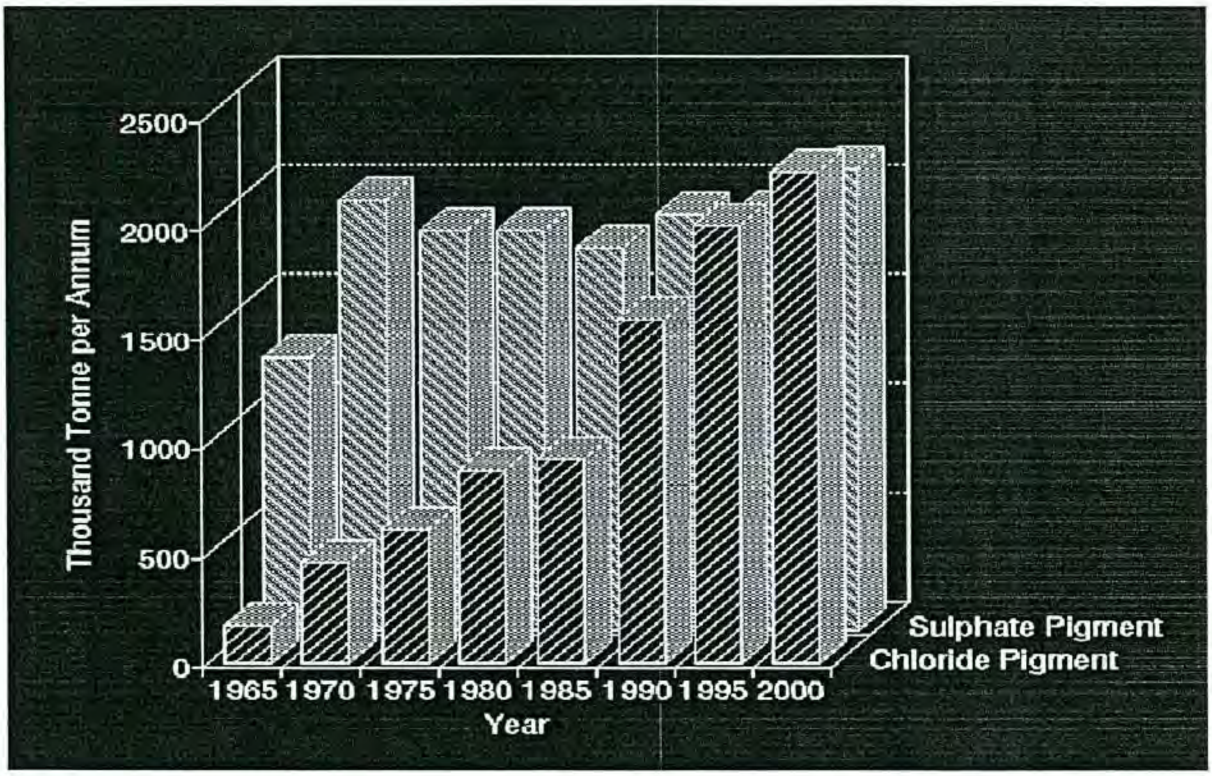

Figure 1.1: World Trend in Pigment Production

For these same reasons, in 1986 Westralian Sands commissioned the existing plant with 100,000 tonnes of synthetic rutile per annum nominal capacity. This project has been both technically and economically successful.

The proposed expansion will increase synthetic rutile capacity to 230,000 tonnes per annum.

1.3 TIMING OF THE PROJECT

Assuming the relevant environmental and government approvals have been obtained by the end of 1992, a submission to the company board will be made in the first quarter of 1993.

Construction activity will commence soon after a decision to proceed. Production will commence 24 months from start of construction. These are minimum times. The short term market for product is weak and commencement of construction will be timed to take best advantage of a predicted economic upturn.

1.4 SCOPE OF THE PROJECT

The scope of the project is based on the expansion of synthetic rutile capacity to 230,000 tonnes per annum.

Buildings and equipment similar to those now installed will be constructed directly adjacent to existing plant.

The proposal involves the construction of:-

- a second kiln and supporting plant.
- a wet processing section of conventional design or based on new technology under development.
- liquor containment and waste handling system.
- relocated and expanded artificial wetland.
- new workshop and office accommodation.

1.5 INTERACTION WITH OTHER DEVELOPMENTS

After expansion of Westralian Sands' synthetic rutile capacity, 410,000 tonnes of ilmenite will be required as feedstock for the expanded plant.

The company does not intend to increase mine capacity but will upgrade some ilmenite currently directed to sulphate pigment producers. Additional feedstock will be purchased from other Western Australian mining companies as required.

This will lead to ilmenite, which is currently exported, to have "value added" within the state. It will also enable the upgrading of some ilmenite mined by other companies.

Synthetic rutile will be sold within Australia and exported overseas.

1.6 RELEVANT LEGISLATION AND THE APPROVAL PROCESS

In Western Australia, the process of environmental impact assessment is formalised by the Environmental Protection Act, 1986.

The full assessment procedure is illustrated in Figure 1.2.

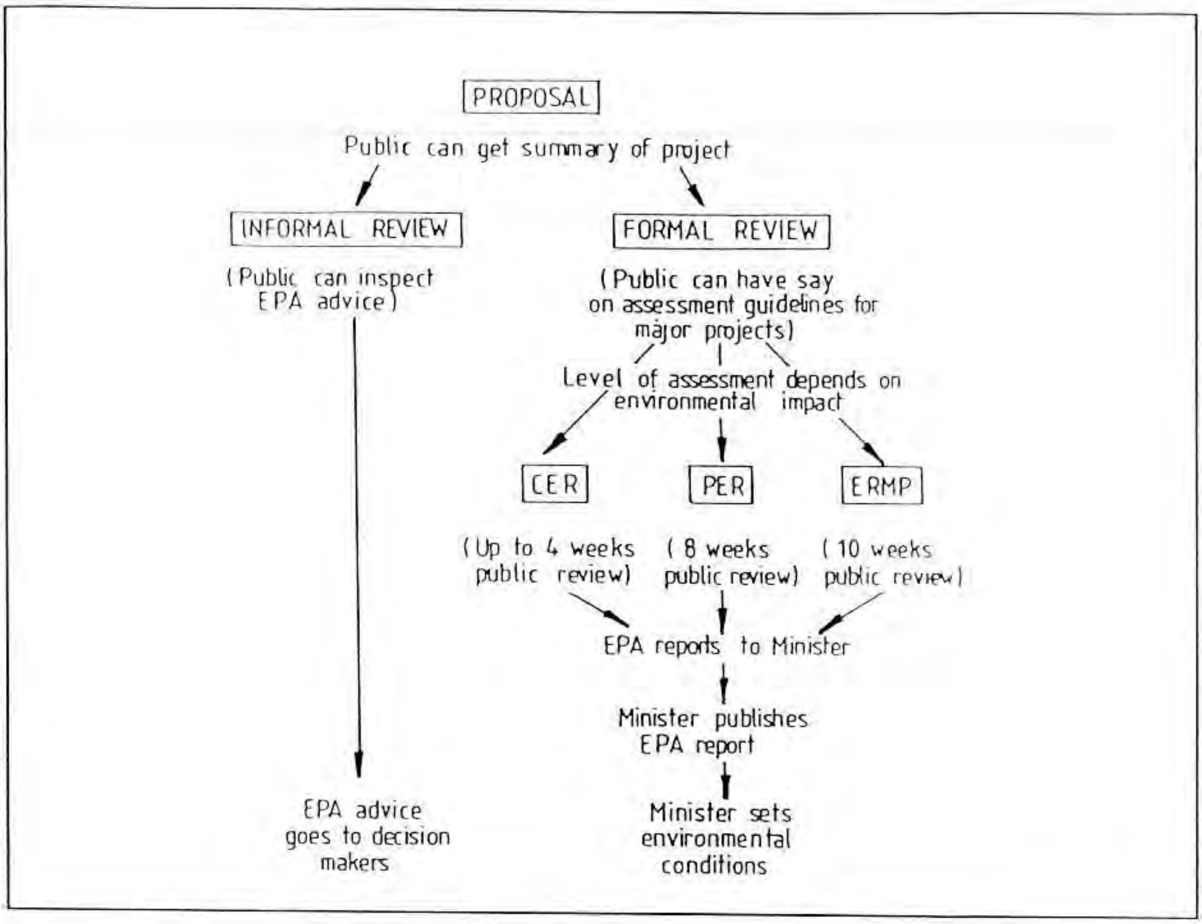

Figure 1.2: EPA Project Assessment

In 1991, Westralian Sands approached the Department of State Development, Mines Department and the Environmental Protection Authority (EPA) for discussions about the project and its options.

A proposal application was submitted in October 1991 to the Department of State Development triggering the process to obtain the necessary governmental approvals.

In October 1991, the EPA advised that the level of assessment for the project's environmental impacts had been set at Consultative Environmental Review (CER).

No appeals were received against this decision.

Guidelines for the preparation of the CER were received from the EPA on 22 November 1991. (The guidelines are included as Appendix 1 of this document.)

This CER is a public document and has been released to members of the public and government for review.

The company has advertised its availability in local newspapers in the Bunbury/Busselton region. Copies of the CER will also be available to community groups, affected residents and local government authorities.

During the public review period, interested people and organisations are encouraged to make submissions to the EPA. This will assist the Authority in assessing the proposal and determining advice to the Minister for the Environment. A guide to the preparation of submissions is included in the preface of this report with further information in Appendix 2.

Issues raised in submissions will be collated by the EPA and will be presented to Westralian Sands for response. WSL's response to the public feedback will allow the EPA to prepare a report to the Minister for the Environment.

Following a period of public appeal on the EPA's Report and Recommendations, the Minister will determine whether the project may proceed and under what conditions.

In addition to obtaining approval under the Environmental Protection Act, 1986, the project will have to satisfy the requirements of other state legislation including:

Aboriginal Heritage Act, 1972 – 1980
Agriculture and Related Resources Protection Act, 1976 – 1983
Bushfires Act, 1954 – 1981
Conservation and Land Management Act, 1984
Country Areas Water Supply Act, 1947 – 1979
Local Government Act, 1960
Mines Regulation Act, 1946 – 1974
Mining Act, 1978 – 1987
Radiation Safety Act, 1975
Rights in Water and Irrigation Act, 1914 – 1981
Road Traffic Act, 1974 – 1982
Soil and Land Conservation Act, 1945 – 1982
State Energy Commission Act, 1979
State Planning Commission Act, 1985
Water Boards Act, 1984
Wildlife Conservation Act, 1950 – 1980

2. NEED FOR THE PROPOSAL

2.1 PROJECT INTERACTION WITH THE TITANIUM DIOXIDE INDUSTRY

Australia ranks amongst the world's top 10 producing countries of titanium dioxide pigment due mainly to Australia's importance as the major producer of titaniferous minerals. Australia also boasts significant long term reserves of these minerals.

There are currently three producers of titanium dioxide pigments in Australia:

- SCM Chemicals Ltd at Kemerton and Australind, Western Australia
- Tiwest Pty Ltd at Kwinana, Western Australia
- Tioxide (Australia) Pty Ltd at Burnie, Tasmania.

Material requirements for pigment production are determined by the two main process technologies: the sulphate process and the newer, favoured, chloride process.

The pigment industry is restructuring as a result of a preference for chloride plants over sulphate plants. The chloride route takes feedstocks with a higher TiO_2 content (rutile, synthetic rutile and slag) and produces less waste. It also involves a higher level of recycling and is regarded as being more environmentally acceptable.

Sulphate plants currently constitute over 50% of world production capacity. The market share of these plants is expected to decline over the 1990s as almost all new capacity will be based on chloride technology (refer Figure 1.1).

High TiO_2 feedstocks such as rutile, synthetic rutile and slag are preferred for the chloride process. Operators are using an increasing amount of synthetic rutile in preference to natural rutile due to the higher cost and reduced supply of natural rutile. Synthetic rutile production stands out as a major growth area for titaniferous minerals.

2.2 BENEFITS OF THE PROJECT

The construction of a second synthetic rutile plant in Capel will require a capital investment of about $100 million. Westralian Sands will aim to maximise the Australian content of project expenditure. (For the existing capacity, Australian content was about 85%.)

The company's nominal synthetic rutile capacity will be boosted from 100,000 to 230,000 tonnes per annum. Export revenue will be $40 million more than if the material was to be exported as ilmenite rather than synthetic rutile.

Up to 200 people would be employed during the two year construction phase and an extra 50 full-time employees would be required on commissioning and operation. Westralian Sands will apply an established local-priority policy to employees, contractors and suppliers. It is expected a significant proportion of the workforce will be derived from the south-west region.

At full production the expanded synthetic rutile plant will spend an estimated $65 million per annum on materials, services and labour. This expenditure will be predominantly within the Capel, Bunbury, Collie and Perth regions.

Following the expansion, the permanent workforce, mostly residing within 25km of the plant site, will earn $4.5 million annually.

Westralian Sands will establish a project office in Bunbury to co-ordinate the planning and design of the plant. The major engineering contractor will also base itself in Bunbury, thereby creating a demand for technical and engineering skills within the local community.

This project reflects Westralian Sands' commitment to value added processing and is consistent with the national strategy to develop secondary processing of Australia's mineral resources. Synthetic rutile has six times the value of ilmenite, resulting in a considerable increase in the nation's earnings. Refining ilmenite to synthetic rutile increases the potential for further processing to titanium dioxide pigment within Australia.

3. EVALUATION OF ALTERNATIVES

3.1 SELECTION OF SITE

The company's existing synthetic rutile plant is located 4.5km north-northeast of the town of Capel.

The site was chosen as most suitable for a number of reasons:

- The site is centrally located in relation to the company's existing and future mine sites, mineral separation plants and the port of Bunbury.
- Close proximity to necessary infrastructure and essential services.
- Road and, potentially, rail access facilitated transport of raw materials and finished product to and from the site.
- The presence of the North Capel mine site allowed the suitable disposal of solid wastes.
- The land was considered to be of poor agricultural value, being very sandy and having very low nutrient levels.
- Westralian Sands owned some 250 hectares of land surrounding the site which could act as a buffer zone for operations.
- At the time, there were no residences within 1.3km of the proposed site and only two within 2km.
- Convenient distance from Bunbury and Busselton, where labour pools may be drawn on and adequate housing available.

Since commissioning the North Capel synthetic rutile plant in 1986, Westralian Sands has purchased some adjacent land and now owns in excess of 500 hectares for plant, buildings and separation from nearby residences. Three new residences have been built within 2km of the plant since it was commissioned.

An expansion of the plant on the existing site utilising developed infrastructure is logical. The experience of the past five years of operations has shown that environmental and social impacts can be successfully managed.

3.2 SELECTION OF TECHNOLOGY

Three economically viable processes have been developed to upgrade ilmenite to synthetic rutile:

- Benelite process – operated in the USA and India
- Rupaque process – operated in Japan
- Improved Becher process – operated in Western Australia

The Becher process was developed in the early 1960s in WA as a result of joint research between the WA Government Chemical Laboratories and Western Titanium (now AMC Mineral Sands Ltd).

The process was specifically designed to utilise local ilmenites and highly reactive Collie coal.

Westralian Sands has been successfully operating a synthetic rutile plant based on the Becher process for six years. The proposed plant will incorporate design efficiencies aimed at minimising wastes, recycling process water where possible, and utilising waste heat. On both environmental and economic grounds the Becher process is the preferred proven alternative.

Over the past 18 months the company has been operating pilot scale trials on a new process. The new process utilises a kiln as in the Becher process but the wet treatment section is significantly different. The new technology may be used if sufficient confidence can be gained in its operation. Throughout the CER, reference will be made to the new process when impacts are different to the conventional Becher process.

3.3 NO DEVELOPMENT OPTION

Should the project not proceed then the following will occur:–

- Ilmenite will continue to be exported to be upgraded overseas resulting in reduced revenues to Australia.

- Ilmenite exports will decline in volume and price over a period of time as consumer markets direct their purchases towards synthetic rutile or substitutes manufactured elsewhere.

- The future of Westralian Sands will decline as its revenue potential is reduced with loss of markets.

- Employment in the Capel, Bunbury region may decline as Westralian Sands' operations contract.

4. LOCATION AND EXISTING ENVIRONMENT

4.1 LOCATION

The proposed site for the synthetic rutile expansion project lies some 4.5km north-northeast of the centre of Capel townsite and some 20km south of the City of Bunbury (Figure 4.1). The site is approximately 1.5km east of the Bussell Highway.

4.2 CLIMATE

The project site enjoys a Mediterranean climate with wet, cool winters and dry, warm to hot summers. Rainfall has averaged 847mm/annum over the 65 years of recordings taken at the Capel Post Office.

Evaporation data do not exist for Capel or Bunbury and the two nearest recording sites are Wokalup near Harvey (55km to the NNE) and Jarrahwood (35km to the SSE). An average of their respective records suggests an average annual evaporation rate of 1,516mm, with an average excess of evaporation over rainfall of 669mm/year.

Average winter temperatures range from 8°C minima to 20°C maxima while average summer temperatures range from 13°C to 27°C. Average daytime humidities range from a low of 59% in January to 75% in July.

Data on wind speed and direction are available from two sources located in the Bunbury area. In summary, strong winds of 30 – 50km/hour are experienced from the north, northwest and west quadrants during winter, whilst summer conditions are dominated by easterly winds in the morning and by south-westerly winds in the afternoon.

4.3 GEOLOGY, LANDFORMS AND SOILS

The project area is located on the Swan Coastal Plain, an area of continental and marine sediment accumulation laying west of the Darling escarpment. The total thickness of sediment exceeds 15,000m in places, representing sedimentary units ranging in age from over 1,000 million years to the present.

In general, continental sandy sediments have high water-holding abilities and form important aquifers. Marine fine-grained sediments have extremely low permeabilities which prevent extraction of their contained water. Such sediments also form barriers to water movement (aquacludes) between overlying and underlying aquifers.

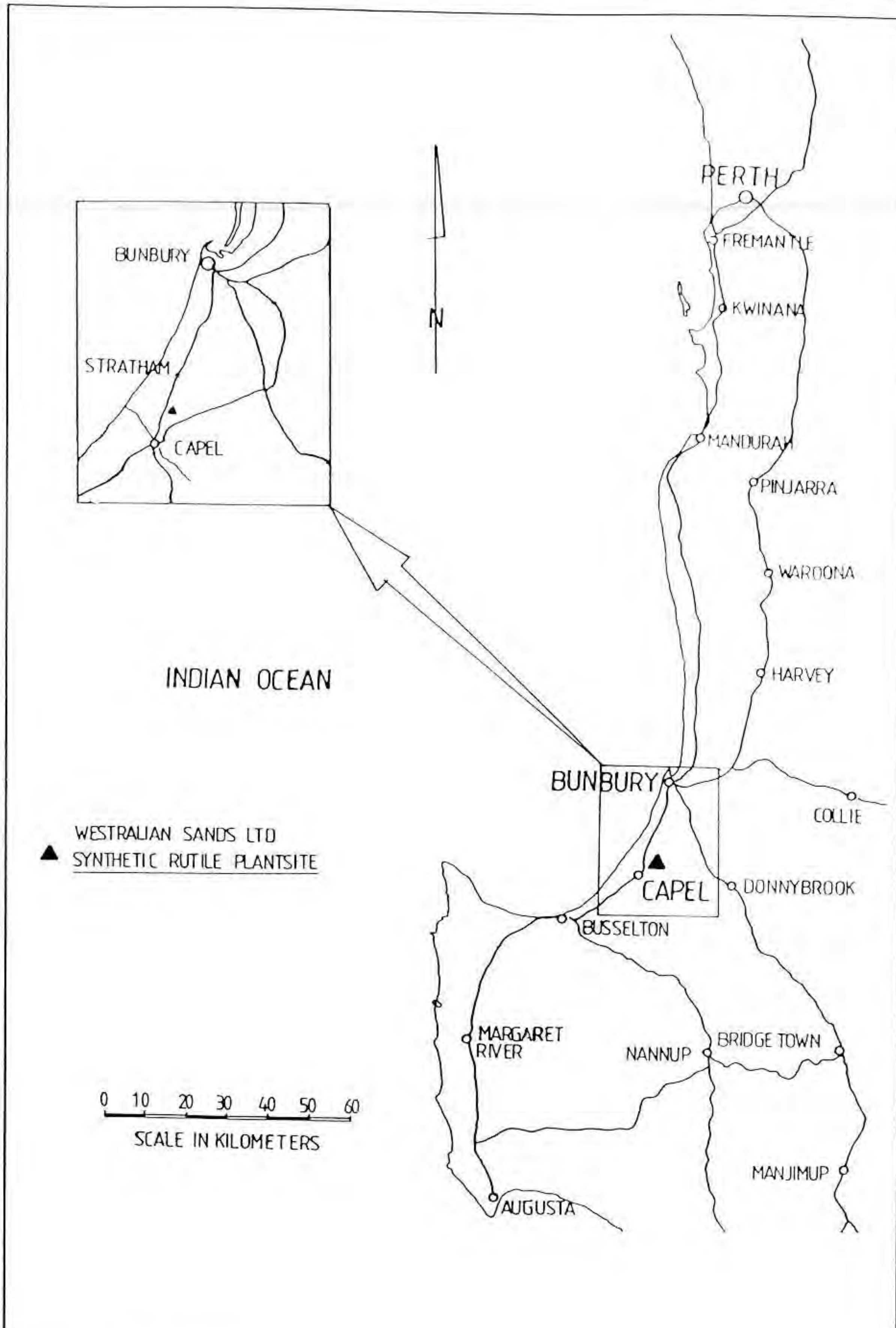

Figure 4.1: Location of the Proposed Project

The following description commences with the deepest (and hence oldest) unit. It is summarised in Figure 4.2. The Yarragadee Formation is at least 900m thick beneath the project area. It is a sandstone unit containing minor shale. It is the current source of water for the North Capel mining operation, the existing synthetic rutile operation and will be used to supply water to the proposed expansion.

The Leederville Formation is about 120m thick. It is composed of sands and clays altered to sandstones and shales. A grey-black micaceous clay averaging 20m thick at the top of the formation and a brown clay averaging 24m thick at the bottom are aquacludes, preventing any vertical water movement. In between are sand units averaging 73m in thickness and these form the major aquifers of the Leederville Formation. A layer of clean sand derived by shoreline processes from the underlying Leederville Formation overlies it. This unit can reach up to 7m thickness under the synthetic rutile plant site.

The large north-south-striking sand dune stands 6-10m above the surrounding surface and contains the heavy mineral accumulation which has been mined since 1964. It forms part of the Bassendean dune system. The dune is the main geological unit of interest, since much of the solid waste disposal and effluent ponds will be located on its surface or flanks.

This sand ridge extends continuously from near the Capel townsite to Stratham. To the west of the ridge, topography is subdued until large sand dunes are encountered next to the present coastline. To the east the flat erosional surface of the Swan Coastal Plain is only occasionally interrupted by low dunes. On both sides of the large dunal ridge, there is a slight decrease in elevation from north to south so that watercourses generally flow to the south.

The youngest geological unit consists of brown/yellow ferruginous sand with pisolitic laterite. It has highly variable clay and silt contents since it is derived from precipitation of iron and aluminium oxides into pre-existing sediments. Over the Bassendean sands, its clay and silt content is mostly less than 5% while, over alluvial clays, it averages about 50%.

The soil horizons developed over most of the subject area are low in organic matter and clay. The soil structure consists of three major horizons from the surface:-

1) Dark grey sand with low to moderate organic matter content and low clay.
2) Orange/yellow sand with minor inclusion of iron oxides.
3) Yellow, parental sand.

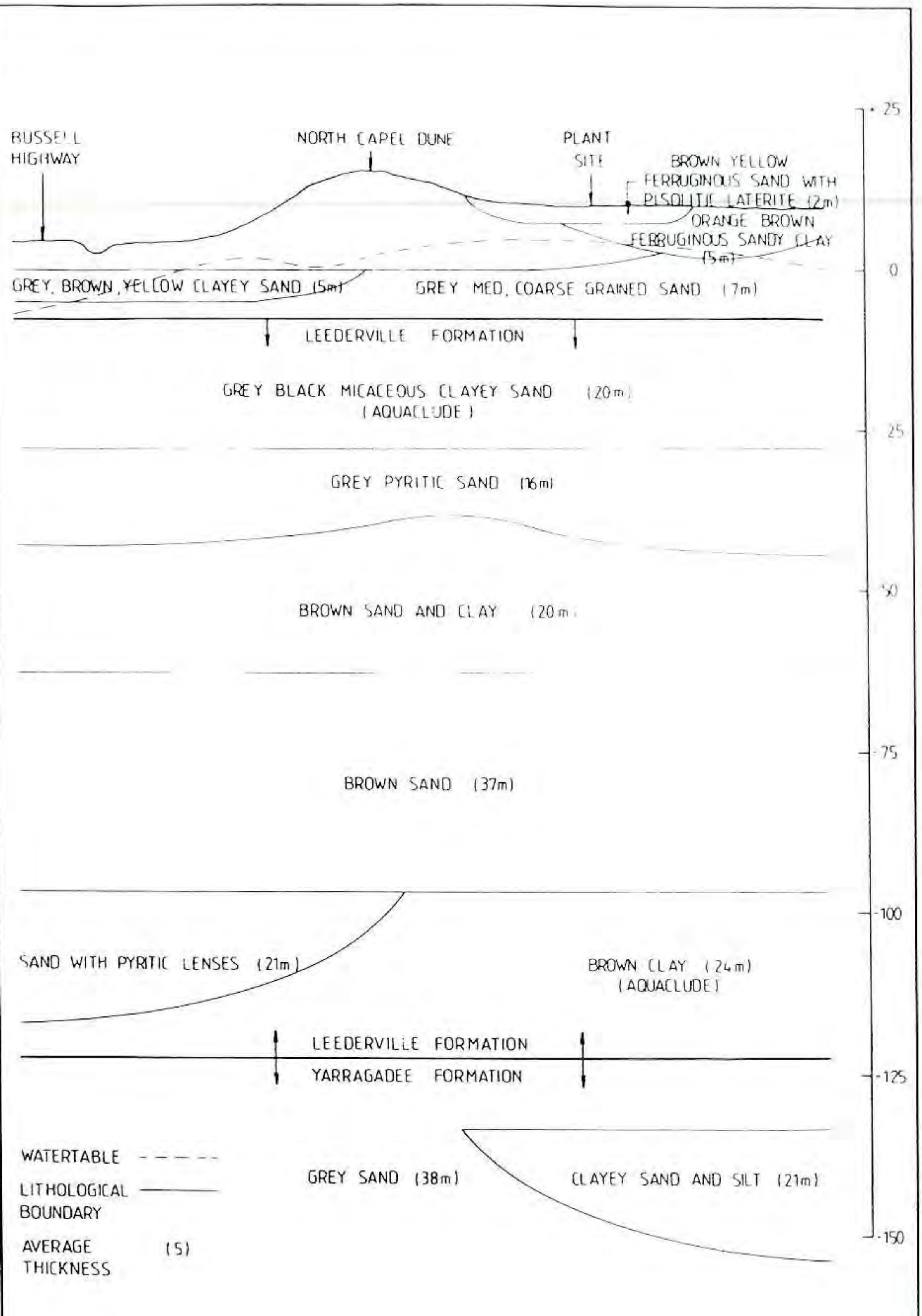

Figure 4.2: Generalised Geological Cross Section of Plant Site

4.4 CURRENT LAND USE

The land directly affected by the proposed synthetic rutile expansion is currently owned by the company with the exception of Yeardy Road which bisects the site. It is immediately adjacent to the existing plant. The current use of the land to be covered by the expanded facility is a mixture of:–

- Industrial storage
- Maintenance workshops
- Roadways – plant access and public road
- Existing production dams
- Cattle pasture

The land to be affected by the synthetic rutile plant is presently covered by mining leases. The company has obtained approval in principle to close Yeardy Road to through traffic with alternative access being provided from Bussell Highway to Railway Road.

4.5 ADJACENT LAND USE

Since European settlement, the area surrounding the plant site has been extensively cleared of native vegetation, and pasture planted for cattle and sheep grazing.

The existing synthetic rutile plant is located on the eastern side of a dunal ridge running north–south (see Figure 4.3).

To the north is a mining pit being used for the disposal of solid wastes.

To the east of the dunal ridge, the principal land use activities are cattle and sheep grazing. Part of the land is owned by the company and part is owned privately.

To the south is Westralian Sands' North Capel mining operation. The land is being progressively rehabilitated to pasture with pockets of native vegetation. Mining is expected to be completed by 1994.

West of the site the dunal ridge is cleared for grazing by cattle and sheep. Areas of the ridge have been planted with mixed native species to improve the appearance and to shield the plant. The Bussell Highway joining Capel and Bunbury passes 1½km to the west of the site and a block of State forest lies 4km to the north–west.

Four inhabited dwellings exist within a 2km radius of the site. The township of Capel lies 4.5km to the south. A rabbit farm is located 2km to the north.

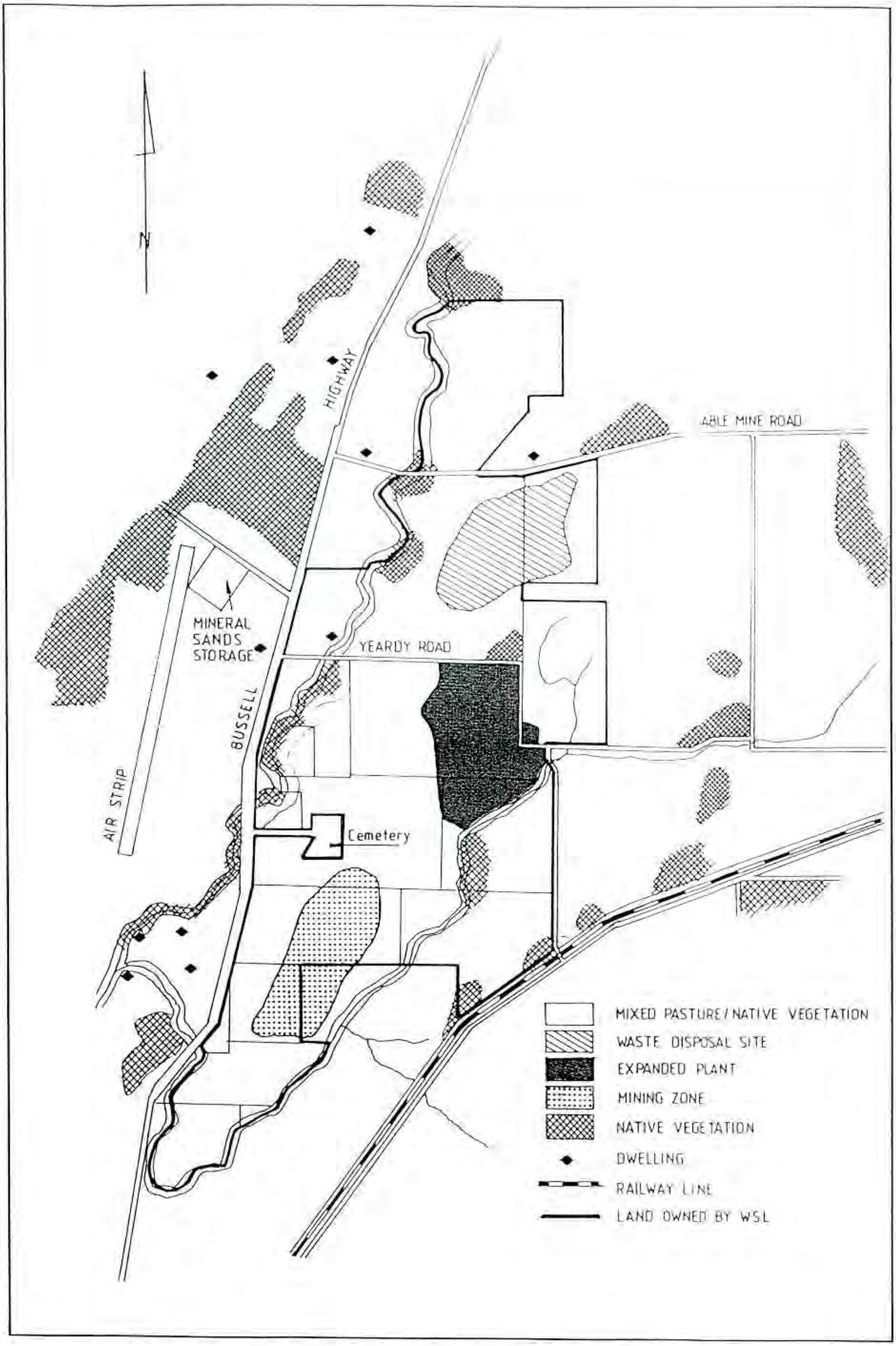

Figure 4.3: Land Use and Ownership

In summary, adjacent land status and uses include:

- mining and mineral processing
- natural vegetation
- mixed pasture and native vegetation
- pasture
- crop

4.6 HYDROLOGY

4.6.1 Surface Hydrology

The combination of high winter rainfall and generally flat topography has created water-logged areas with few major water courses. Purpose built drains remove water during the winter months.

Immediately to the south east of the synthetic rutile plant site, the Elgin Drain carries water from the upper reaches of the Gynudup Brook (Figure 4.4) as well as water from low-lying areas immediately north and south of the drain. West of the bridge on Bussell Highway, the drain gives way to a wider, shallower tree-lined creek which maintains a few permanent pools in summer.

On the western side of the sand ridge, Gynudup Brook carries winter run-off from a wide area extending northwards to Stratham and eastwards to Gwyndinup. The Brook has a comparatively low annual flow. Over the last 20 years it has received additional quantities of high quality water by seepage and discharge from mining operations.

The Capel River flows into Geographe Bay via a man-made cut through the coastal sand dunes. It is a significant watercourse draining an area of some 616 km^2 [1]. In its lowermost reaches, artificial embankments have been placed on both banks to prevent flood overflow. The Capel River forms a continuous pool from its mouth almost to the edge of the Capel townsite. Although data are lacking, maintenance of summer water levels has been assisted by water discharges from mineral sand mining and processing plants within the Capel area. Some 600m upstream of the mouth, a small weir prevents salt-water backflow from mixing with fresh water downflow.

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[1] Public Works Department, 1976, Water Resources Section, Planning Design and Investigations Branch, Stream Flow Records of Western Australia for 1975, Public Works Department, Western Australia.

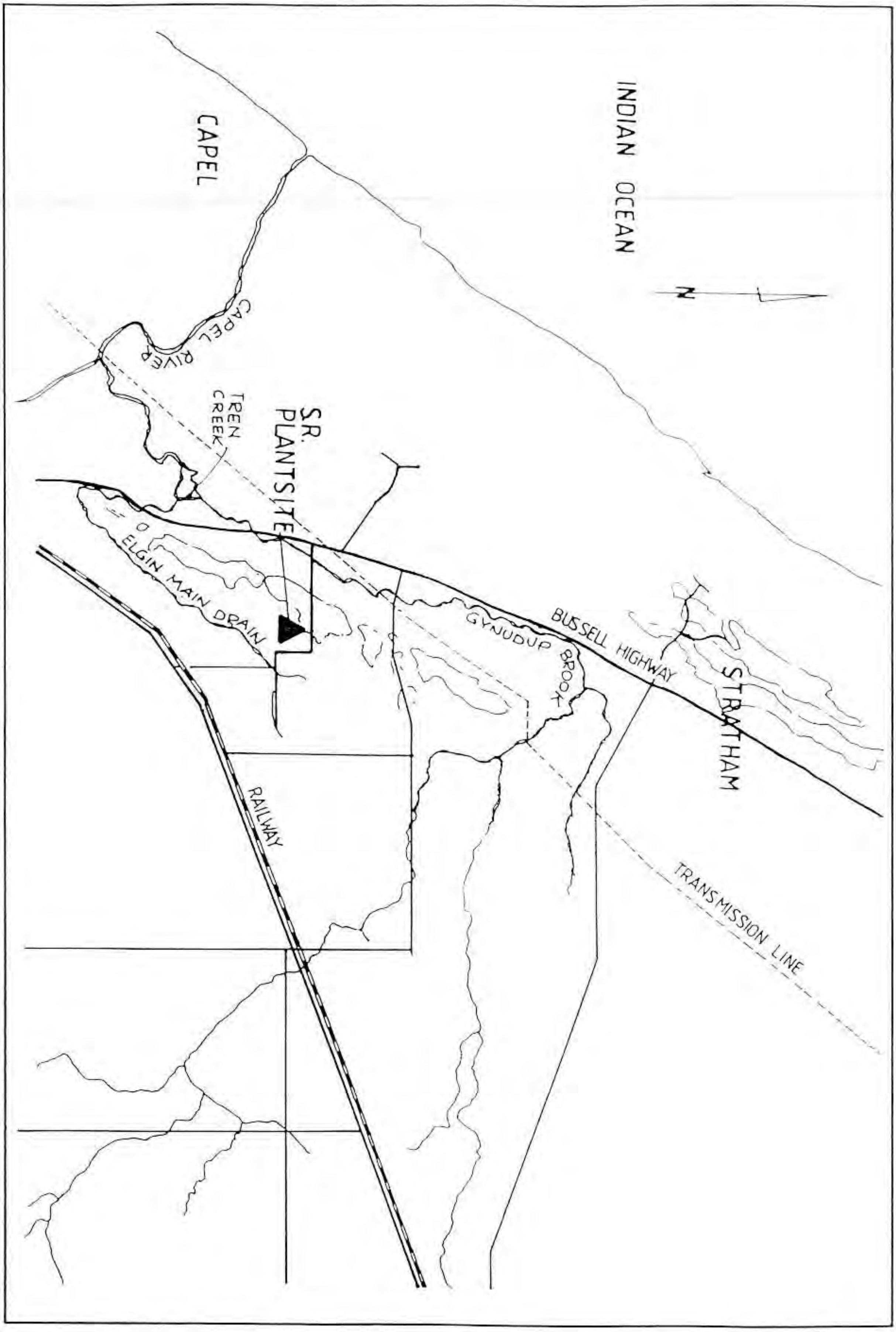

Figure 4.4: Surface Water Drainage System North of Capel

4.6.2 Ground Water Hydrology

The geological cross-section shown in Figure 4.2 gives a generalised view of watertables in the area. East of the dunal ridge, the watertable is relatively shallow at about 6 metres. Under the sand dune the depth to the watertable is up to 11.5m. To the west, it is again at about six metres depth. Tests on typical dune sand indicated a horizontal ground water flow in the order of 112m/year. With an average dune width of some 500m, it would take some 4.5 years for water entering the dune's eastern surface to reach the western side. Water discharged into the top of the dune would take between 2 and 2.5 years to exit at the western toe.

For the ferruginous and lateritic soil units a flow rate in the order of six metres per year is likely whilst most other sediments are likely to have flow rates from one metre per year down to 0.0004 metres per year.

Water entering the dunal sands will gravitate to the underlying clay sediments and then flow horizontally.

The following features are relevant to the management of site spillage so that the impact will be localised to the superficial formations and would spread slowly making good recovery possible:

- An aquaclude beneath the entire project area controls the watertable.
- The predominant water flow is from east to west, although there is likely to be a small north to south flow on the east side of the dune.
- The addition of large volumes of water to the sands would cause water to flow out of the western edge of the dune within a few years.
- Water added to the ground water system is believed to divide into two separate flows. One flow is to the west and south, emptying into the Capel River and the Stirling Flats. The second flow is diverted to small surface swamps along the western edge of the dune.

4.6.3 Ground Water Quality

89 bores have been installed in the synthetic rutile plant area in order to detect contamination of the surface aquifers.

An established monitoring programme results in the monitoring bores being regularly sampled.

Base data was collected from monitoring bores prior to commissioning of the existing plant and indicated water suitable for agricultural purposes. The bores monitor the surface aquifer only and stop at the aquaclude above the Leederville Formation. Within the surface aquifer, bores monitor at shallow, medium and deep levels. Prior to the existing plant operation, water quality varied around the site and with depth. Generally the water was acidic and acidity increased with depth. Salinity also increased with depth, shallow bores showing total dissolved solids level around 300 mg/m^3 while deep bores yielded a level around 1,500 mg/m^3. Salinity was due predominantly to alkaline and alkaline earth chlorides with some sulphates.

Since commissioning, all samples have shown reduced acidity with many bores approaching neutral. Salinity has been unchanged except around the ammonium chloride liquor dams where some elevated readings have been recorded on shallow and medium depths. Shallow and medium depth sulphate levels have risen as have iron and manganese levels.

In general the surface ground water is still suitable for agricultural purposes.

In the five years of plant operation the following trends have been noted:

- Ground water has become less acidic and is closer to neutral throughout the superficial formations.
- Total dissolved solids have risen around the ammonium chloride dams where leaks have occurred. (Recovery procedures are in place to extract high salinity water.)
- The ratio of sulphate to chloride has risen marginally except where chloride leaks have been experienced.
- Iron and manganese levels have risen at shallow monitoring points particularly in the area where leaks have occurred.

4.6.4 Ground Water Demand

Westralian Sands operates a borefield to supply ground water for the existing synthetic rutile plant. The borefield comprises 5 bores in the Yarragadee Formation. Westralian Sands is licensed by the Water Authority to draw up to 2.7×10^6 kl of ground water per annum.

In May 1990, consultants GRC - Dames and Moore were commissioned to conduct recovery tests on the SR plant borefield to provide information for an internal assessment of the current status of the Yarragadee Formation aquifer.

The report concludes:

> "The recovery tests indicate that water levels in the Yarragadee Formation aquifer have not declined significantly in the area of the Westralian Sands SR plant since 1977. Water levels during steady pumping in the existing production bores are less than 20m below natural surface and water levels recover to within 2.5m of the last recorded static water levels within 6 hours of shut-down. Extrapolation of the recovery data indicates that water levels would recover to within 0.47 and 1.11m of the last recorded static water level within 365 days. Ground water levels may in fact have declined since these static levels were obtained, in which case full water level recovery may in fact take less time than is indicated.
>
> Ground water level monitoring data from Water Authority bores at Capel, 4.5km to the southwest, suggest there has been a local net decline in water levels in the Yarragadee of perhaps 2 to 3m during the past 10 to 12 years at Capel. This suggests that at least a small decline in water levels at the SR plant is likely to have occurred over the last 10 to 12 years, either as a result of the pumping at Capel town or as part of a broader regional trend.
>
> On the basis of the recovery test results, the aquifer is performing well within its capacity and a significant increase in the annual abstraction may be viable."

A further report (Appendix 3) indicates that the proposed extraction will be adequately sustained by the aquifer.

4.7 AIR QUALITY

Air quality in the region is typical of a rural environment with scattered industry. The major impacts would be those from existing mining and refining, traffic on the Bussell Highway and impacts of agricultural practices. Dust and odour are the more noticeable air quality impacts while sulphur dioxide emissions from the process present a potentially significant impact which is not detectable without sensitive monitoring equipment.

4.7.1 Sulphur Dioxide

Sulphur dioxide is a colourless gas which has a sharp acidic odour when present in concentrations above several thousand microgrammes per cubic metre of air. In the industrialised areas of the northern hemisphere it is a major contributor to acid rain.

The World Health Organisation's "Air Quality Guidelines for Europe"[2] suggests that 'the lowest observed effect level of concern to health' is 1000 $\mu g/m^3$ (10 minutes). On this basis a factor of one half this value – 500 $\mu g/m^3$ (10 minutes) is considered a reasonable aim. A corresponding 1 hour value for exposure would be 350 $\mu g/m^3$. The EPA WA has used this latter figure in studies on the Kwinana[3] area and has proposed an environmental protection policy to make 99.9% compliance with the 350 $\mu g/m^3$ limit enforceable by law.

Computer modelling of emissions to predict ground level concentrations of pollutants is a widely used and generally well accepted technique for evaluating impacts. Such modelling indicates that in extreme situations the current emissions from the North Capel site may reach or exceed 350 $\mu g/m^3$ at the northern and north western boundary of the site.

Concern with the finding prompted Westralian Sands to purchase a mobile environmental monitoring station in June 1991 and position it at a site 1.5km north of the synthetic rutile plant. The position chosen for the monitoring station was at a likely worst impact location based on modelling. Ground level sulphur dioxide concentrations and wind data are recorded at the site.

In the nine months from July 1991 to March 1992, the 350 $\mu g/m^3$ reference level has been exceeded three times. The highest hourly average recorded was 359 $\mu g/m^3$. While the readings indicate compliance with the environmental protection policy, it is clear that the impact of another close source of SO_2 emission will require careful investigation and management.

4.7.2 Dust

The area supports rural, mining and processing activities. Dust would be generated by these activities continuously and intermittently. The existing synthetic rutile operations

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[2] World Heath Organisation, <u>Air Quality Guidelines for Europe</u> Regional Publications, European Series No.23, World Health Organisation Regional Office of Europe, Copenhagen.

[3] Environmental Protection Authority, Western Australia, 1989, <u>Draft Environmental Protection Policy for Sulphur Dioxide and Dust in the Kwinana Region</u>.

present opportunities to impact the air quality through stack emissions and through wind borne dust at the site.

Controlled Emissions

Three stacks emit gases which contain dust (referred to as particulate). These emissions are licensed at 300 mg/m^3. Testing has been carried out at regular intervals and has shown the emissions to be well within the limit. Further testing of the particulate has been done to check for toxic components. The emissions satisfy National Health and Medical Research Council guidelines[4] on all components investigated. The existing stacks service wet scrubbers and so give a visible steam plume which dissipates at a distance from discharge depending on humidity and temperature at the time.

Ground Level Air Quality

Air sampling is carried out around the site for occupational health purposes. Dust measurements have been recorded ranging from 40μg/m^3 to 320μg/m^3 and averaging 120μg/m^3. No licence conditions are imposed on this item but some minesites have limits of 1.0mg/m^3 consistent with the absolute limit in the environmental protection policy.

Wind blown dust from the plant and unsealed roadways will not impact beyond the company's boundary.

The North Capel disposal site presents more opportunity for impact. The large portion of waste is very fine and although damp when placed, it will dry out and can be mobilised by equipment movements and wind. Some measurements have been taken just beyond the northern boundary and indicate dust levels at 40μg/m^3. This level is less than the 250μg/m^3 suggested by Lawther[5] as being distressing to humans and the standard of 90μg/m^3 in the environmental protection policy.

4.7.3 Smells and Odours

The existing synthetic rutile plant may impact on air quality in a number of ways:

Incomplete combustion of coal

Coal burnt in the production of synthetic rutile may produce a noticeable odour due to

[4] Australian Environment Council, National Health and Medical Research Council, 1986, National Guidelines for Control of Emissions of Air Pollutants from Stationary Sources. Australian Government Publishing Service.

[5] Lawther P J, Waller R E and Henderson M, Air Pollution and Exacerbation of Bronchitis. Thorax 25:525-539

incomplete combustion. When insufficient air or oxygen is available, unburnt material may give rise to a smell typical of steam trains or domestic coal fires.

Hydrogen sulphide production

Hydrogen sulphide (rotten egg gas) is generated during two phases of the synthetic rutile process. It is generated in the kiln and in the acid leach section. Normally the gas is contained and directed to the kiln after-burner where it is burnt with excess air to produce water and sulphur dioxide.

Control difficulties or equipment malfunction may result in a release of gas containing hydrogen sulphide. Prompt action is taken to restore satisfactory control or rectify malfunctions in equipment. Impacts of this type are infrequent and of short duration.

Mercaptans

Shortly after commissioning the synthetic rutile plant in 1986, a strong odour, attributed to the presence of mercaptans, was noticed.

Mercaptans are a family of naturally occurring substances which contain sulphur. They are produced by anaerobic bacteria which are present in deep aquifers and in stagnant surface waters.

Untreated water from the Yarragadee formation being used in the process contains abundant anaerobic bacteria and blue-green algae (a food source for the bacteria).

Conditions in the plant were suitable for bacterial activity and resulted in the production of mercaptans.

The problem has been controlled by installing a water treatment unit to kill and filter out the bacteria. However, bacterial spores are abundant and may be blown into the water after treatment. Some modifications have been made to areas in the process where conditions were suitable for bacterial growth. Two complaints relating to the one incident have been received in the last twelve months and are most probably due to mercaptan production.

The build up of blue-green algae and anaerobic bacteria in swamps and stagnant areas of nearby waterways is not uncommon, particularly in summer. This is a natural phenomenon helped by nutrients from farming and grazing which can be noticed particularly if an affected drain or swamp is disturbed.

4.8 NOISE

Noise is generated by the existing synthetic rutile facility, mining and processing operations and the Bussell Highway traffic. Within the existing facility the main noise generators are large motors, pressurised air moving equipment, fans and vibrating equipment.

Noise levels from the movement of large volumes of pressurised air in the aeration section are the focus of a noise reduction campaign. An ongoing programme will reduce plant noise to more stringent occupational requirements with consequent benefit to the neighbourhood.

Current noise levels generated by the existing synthetic rutile plant and dry separation plant are regularly monitored by the company.

No complaints have been received by Westralian Sands or the local shire from the local community in the last 12 months.

Noise level contours for the existing plants have been modelled and are illustrated in the consultant's report (Appendix 4).

4.9 SERVICES

The area is serviced by a major highway, the Bussell Highway, and a network of local permanent roadways.

Power is supplied by the southwest electrical grid with 66 kV and 22 kV power lines reaching the site.

Water is drawn from the Leederville and Yarragadee Formation running beneath the proposed plant site to service local industry and residences.

Sewerage, where necessary, is by septic tank systems.

4.10 TRANSPORT

The existing synthetic rutile operations involve transportation of inputs and outputs by road trucks.

The site is serviced by the Bussell Highway which is currently being upgraded to a dual carriageway between Bunbury and Capel.

The highway acts as a major arterial route running north–south servicing the South–West region. Products such as mineral sands, cattle, timber, potatoes, fruit and general supplies are regularly transported by road. Tourist traffic accessing popular destinations further south is seasonal and has increased significantly in recent years.

Traffic movements associated with Westralian Sands' existing mining and mineral processing operations are shown on Figure 4.5.

4.11 SOCIO-ECONOMIC ENVIRONMENT

Demographic Profile

The South–West is the most densely populated rural region of Western Australia. In June 1991, the region's population was estimated to be 134,625.

Bunbury, the region's port and principal urban area, is the focus of commercial, service and administrative activities.

The Greater Bunbury area, encompassing the City of Bunbury and the townships of Australind, Eaton and Gelorup has experienced significant population growth in recent years. Nearly 36,000 people (or approximately 30% of the total South–West population) are concentrated in the Greater Bunbury area.

Economic Profile

Economic activity in the Bunbury–Capel area has historically been based on primary activities with dairying, beef, fruit, vegetable and wool production being prominent.

Through the 1960s and 1970s the economic base broadened to include mining and mineral processing.

More recently the Bunbury region has experienced rapid development in response to demand for services to cater to the restructured regional economy.

Tertiary level activities, reflecting this development, are concentrated in Bunbury and include:

- The Port of Bunbury
- Health Services
- Education and Employment Training

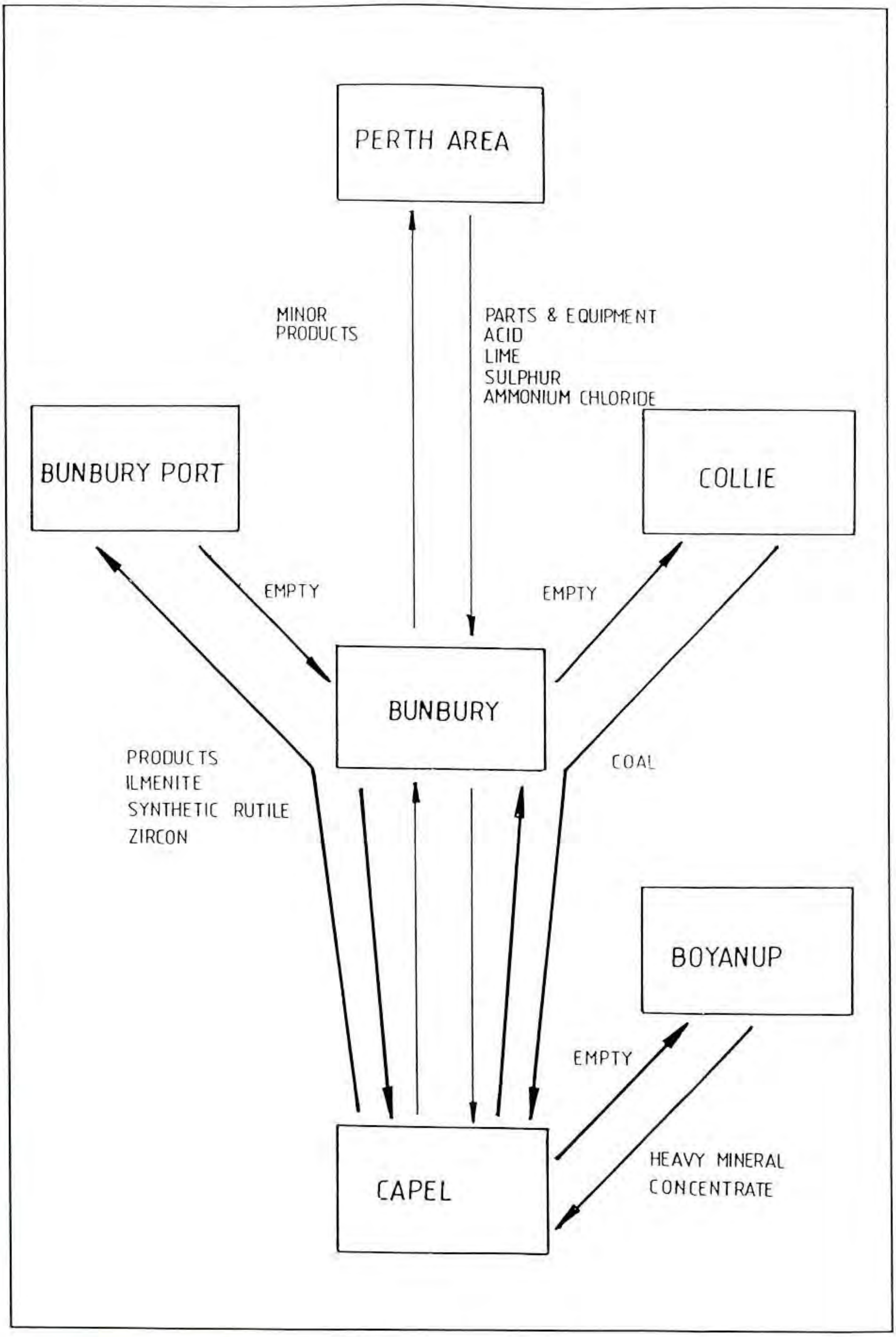

Figure 4.5: Road Transport Movements

- Industry Support Services
- Wholesale and Retail Trade
- Banking and other financial services
- Tourism
- Water and Land Management
- Transport and Communication
- Public Administration and Community Services

The Titanium Minerals Industry in Western Australia is located in two areas; north of Perth to Geraldton and the South-West region.

Western Australia is the world's most important producer of mineral sands and a major producer of refined or processed mineral products. WA has 25% of the world zircon market, 14% of the sulphate pigment feedstock market and 27% of the chloride pigment feedstock market. Western Australia has a small but significant share of the world's $7 billion per annum titanium dioxide markets.

Since 1986 more than $700 million has been invested in value-adding processing of mineral sands in WA. Apart from the significant increase in the value of Australia's export, the investment increases the level of local employment. For every person working to mine ilmenite, two more are required to produce synthetic rutile and six people are employed to convert synthetic rutile to titanium dioxide. (Downstream processing provides the added benefit of more diversified technology.)

The increasingly sophisticated procedures for mining, separation, refining and product manufacture require extensive skills and training. The human resource impact is clearly evident in development of facilities and services offered in centres like Geraldton and Bunbury.

Mineral sands production and processing for the state in 1991 was valued at $600M.

Employment

The Greater Bunbury area in June 1991 had a workforce of 15,118 persons of whom 11% or 1,663 persons were unemployed. Since June 1989 the unemployment rate has increased from 6%. Indications suggest that the situation will deteriorate further before an improvement is observed.

In Capel in June 1991 the workforce comprised 2,843 persons of whom 199 or 7% were unemployed. The unemployment rate has increased from 4.2% in June 1989.

Direct employment in the South-West Titanium Minerals Industry in 1991 totalled about 1,200 persons.

Housing

The City of Bunbury has an existing supply of approximately 3,500 residential lots which is anticipated to accommodate the forecast growth for the next twenty years.

Houses are readily available for purchase in the Bunbury, Capel area. A local real estate agent's estimate indicates approximately 140 houses are listed for sale.

Temporary accommodation primarily consists of rental accommodation, short term caravan, cabin and hotel/motel accommodation.

Rental accommodation is estimated to be in the vicinity of 800 dwellings.

In the Greater Bunbury area an estimated 630 hotel/motel rooms and 660 caravan sites are available plus 106 caravan park vans and cabins accommodating up to 420 people.

Community Facilities and Services

Bunbury is the regional centre for the South-West. Since 1983, Bunbury has been targeted for the Government's decentralisation programme aimed at creating an alternative urban centre to Perth.

Bunbury has undergone major structural changes to roads and port facilities, the growth of a strong industrial and service base and decentralisation of regional offices for many Government agencies.

Bunbury is well served with community and service facilities including schools, medical services, sporting and cultural facilities and communications links.

The City of Bunbury contains 7 primary, 2 secondary and 3 non-government schools. The Shire of Capel contains 2 primary schools and 1 non government school. In addition to these facilities, the South West College of Technical and Further Education and a branch of the Edith Cowan University provide opportunities for higher education and training.

In Bunbury there are two major hospitals plus extensive services offered by private medical specialists and general practitioners.

5. THE PROPOSAL

5.1 CONSTRUCTION

The proposal will involve a construction phase of about 2 years. Activity during this time will build up to a peak and will taper off after commissioning commences. Figure 5.1 shows a typical construction cycle with employment rising to 200 persons. This should be compared with activity during the four week annual maintenance shutdown when similar numbers are involved. The company will plan maintenance shutdown on the existing plant to occur on the shoulder of activity for construction.

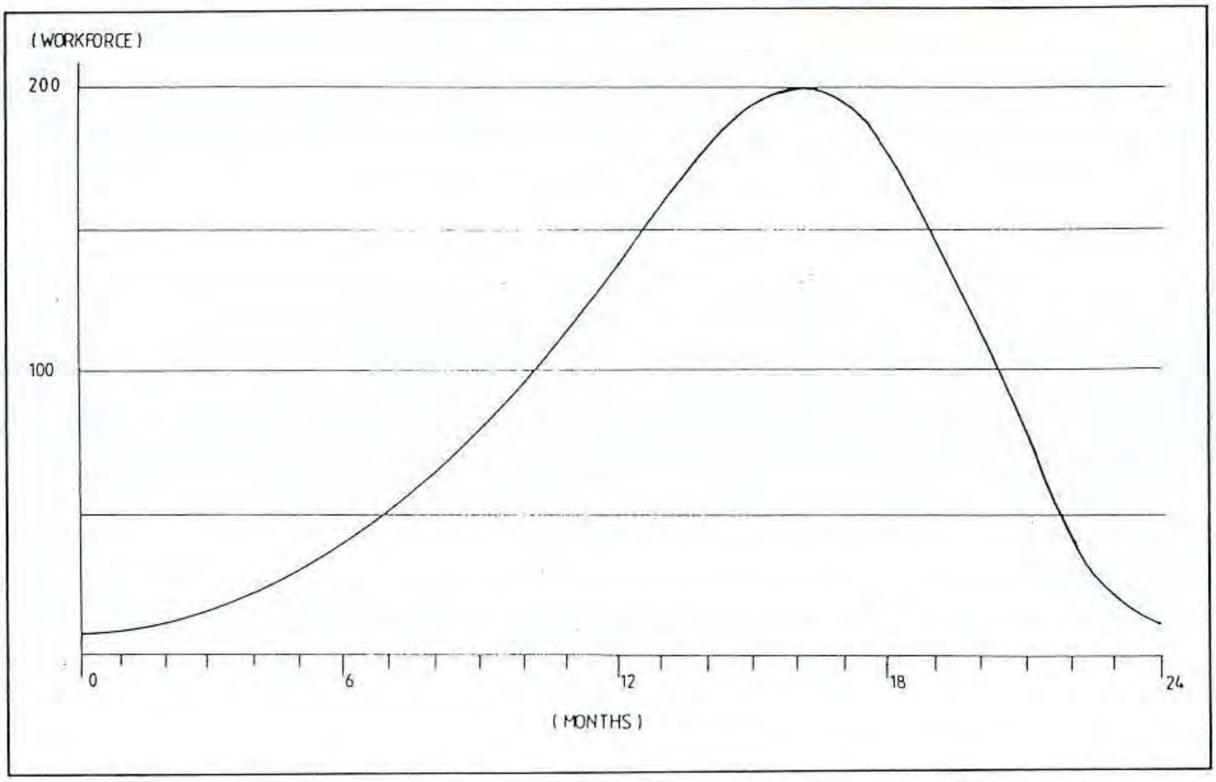

Figure 5.1: Projected Employment during Construction Phase

Some large equipment will be brought onto the site and will meet the requirements of the Department of Transport with respect to time of travel and escorts. The roads from Perth to the South-West frequently carry large mining, earthmoving and industrial equipment.

The main construction activity will take place to the east of the existing facility and will involve ground levelling and excavation, foundation sinking, building erection, equipment installation and servicing. To the south and west, containment dams will be constructed. Figure 5.2 shows the layout of the main construction area to the east of the existing facility. Figures 5.3 and 5.3a show existing and proposed expanded plant.

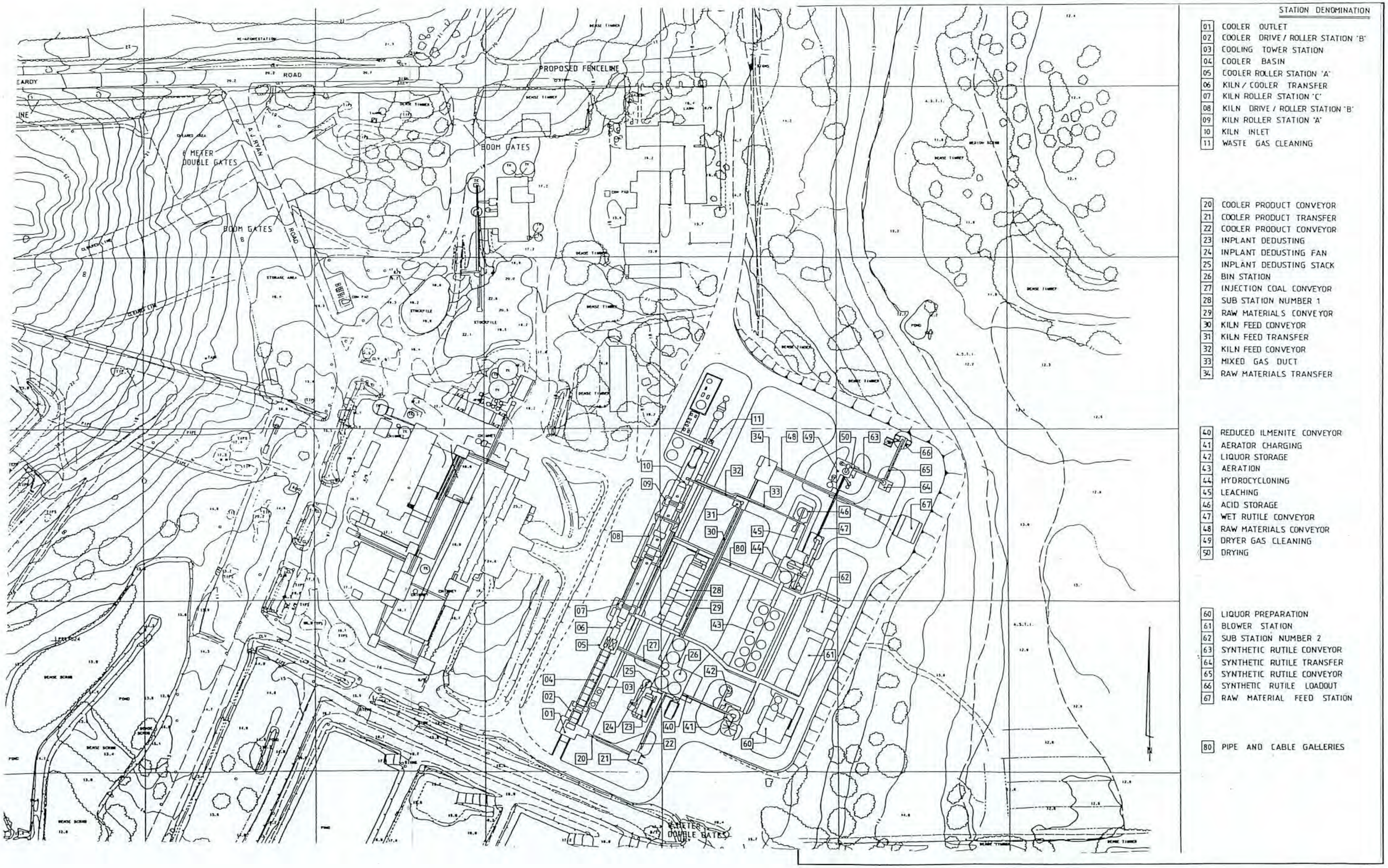

Figure 5.2: Synthetic Rutile Expansion – Locality of Structures

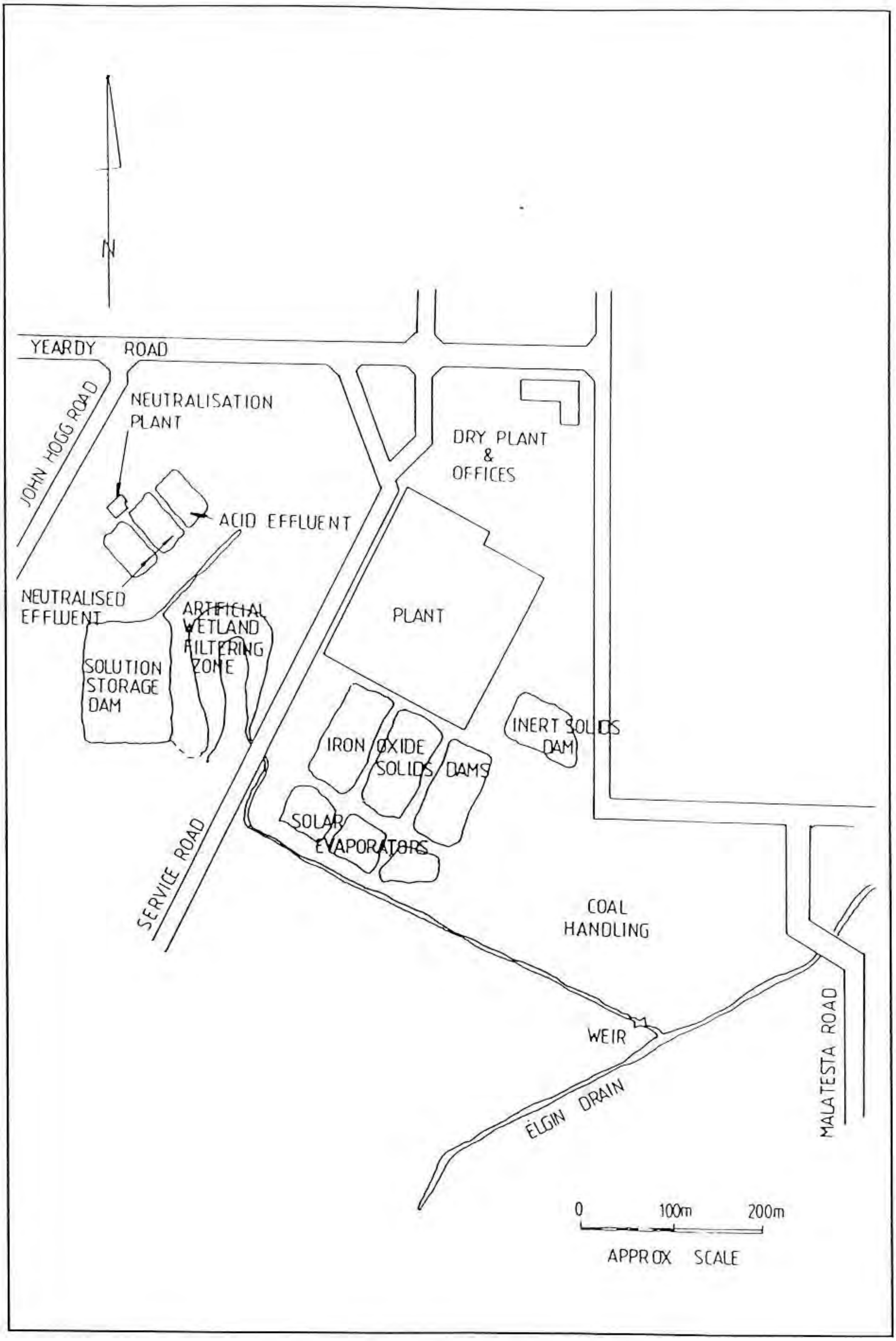

Figure 5.3: Existing Plant Layout

5.2 RAW MATERIAL CONSUMPTION, TRANSPORT AND STORAGE

Ilmenite

Annual ilmenite consumption will increase from 180,000 to 410,000 tonnes. Ilmenite is produced at the North Capel dry plant and at the Capel dry plant, 5km south of the proposed North Capel site. The material is transported by covered road trucks and stored in a bin having storage capacity for 24 hours production. Total expanded storage capacity will be 1,400 tonnes.

Ilmenite feedstock will be supplemented by purchasing from other companies. Ilmenite obtained elsewhere in the South–West will be transported by covered road trucks. More distant sources will be serviced by transport method agreed with or permitted by the Department of Transport.

Coal

Annual coal consumption, including coal for dry plant operations, will increase from 105,000 tonnes to 200,000 tonnes. Coal will be received by covered road truck from Collie on a 5 day per week, 21 loads per day basis. The coal will be stored in plant bins or in open stockpiles containing up to two weeks supply (approximately 10,000 tonnes). Collie coal has the potential to ignite spontaneously in stockpiles but this can be minimised by building low contained and compacted piles. Regular inspections ensure that hot spots are removed and buried.

Sulphuric acid

Annual consumption of sulphuric acid will increase from 5,000 tonnes to 10,000 tonnes. It will be transported in dedicated road tankers from Kwinana, conforming with regulations covering the transport of dangerous goods administered by the Department of Mines. It will be stored in bunded tanks on site. Storage will accommodate 275 tonnes of acid. Bunding will contain 100% of the volume of the tanks it services.

Sulphur

Annual sulphur consumption will increase from 2,500 tonnes to 5,000 tonnes. The sulphur will be transported in 38 tonne covered road trucks from Fremantle or Kwinana. It will be stored on a solid, bunded base, under cover. If stockpiled in the open the area will be continually drained to the acid effluent treatment system. Sulphur may be purchased on an as required basis in which case stock holding will be in the order of 100 tonnes. Alternatively the sulphur may be purchased as a large portion of a shipment in which case up to 1,500 tonnes may be stored.

Lime

Quicklime consumption will not increase from 4,000 tonnes per annum. The lime will be transported by road in 40 tonne sealed tankers from Kwinana and stored in a silo with 100 tonne capacity on site.

Limestone

Limestone is not used in the existing operations however, after the expansion, annual consumption will be 20,000 tonnes. It will be transported by covered road truck from a local source and stockpiled on site. The local stockpile may be large (5,000 tonnes) at times to accommodate the supplier's ability to service seasonal agricultural requirements.

Ammonium chloride

Ammonium chloride consumption will increase from 400 tonnes to 800 tonnes per annum. It will be transported on flat top semi-trailers in 1 tonne bulk bags and will be stored under cover in a bunded area on site. Up to 50 tonnes will be stored at any time.

The new technology does not use ammonium chloride.

Oxygen

The new technology under investigation by Westralian Sands utilises oxygen at concentrations of 90% to 99%. Consumption will be at the rate of 15,000 to 35,000 tonnes per annum. This requirement will be met by on-site manufacturing facilities using the well established cryogenic or pressure swing absorption (PSA) process. It is possible that from time to time transportation of oxygen to or from other site producers or users may occur. If this eventuates then oxygen movements will be conducted by haulage contractors utilising specifically designed tankers and will follow all the required safety procedures for liquid or pressurised oxygen. The existing pilot plant is serviced by a 40,000 litre liquid oxygen storage tank.

L.P.G.

L.P.G. in the form of Butane will be utilised in two areas on an occasional basis

a) Initial kiln heat up following major maintenance shutdowns.

b) As an aid to combustion control in the kiln after-burning section.

The use of L.P.G. on a continuous basis to provide heat for synthetic rutile drying is also under consideration.

The L.P.G. will be supplied to the site by road tanker in unit quantities of 20 to 30 tonnes and unloaded into a specifically design storage facility of 50 tonne capacity installed with vaporiser and regulator set.

5.3 THE PROCESS

Overview

The proposed synthetic rutile plant expansion is based on the successfully operating plant commissioned in 1986 and pilot scale work undertaken since 1991.

Engineering design and process improvements will be incorporated into the project utilising experience and expertise gained from the original operation and technological developments in industry generally.

The proposed expansion will enable 410,000 tonnes of ilmenite to be upgraded to 230,000 tonnes of synthetic rutile per annum.

5.3.1 Traditional Process

The Becher process converts ilmenite feedstock to a product with 90 – 95% titanium dioxide, called synthetic rutile or upgraded ilmenite.

Main stages of the process are as follows:

. Reduction of iron oxide in ilmenite to metallic iron.
. Treatment of waste gases from the kiln.
. Separation of kiln discharge material.
. Oxidation of the metallic iron to form new but physically separate iron oxide particles.
. Acid leaching of the upgraded ilmenite to remove manganese and any residual iron.
. Synthetic rutile product drying.
. Acidic waste neutralisation.

A flow sheet of the process is given in Figure 5.4. A table of gas discharges is presented in Table 5.1.

The alternative process replaces the oxidation and acid leach steps with a single leach stage described later.

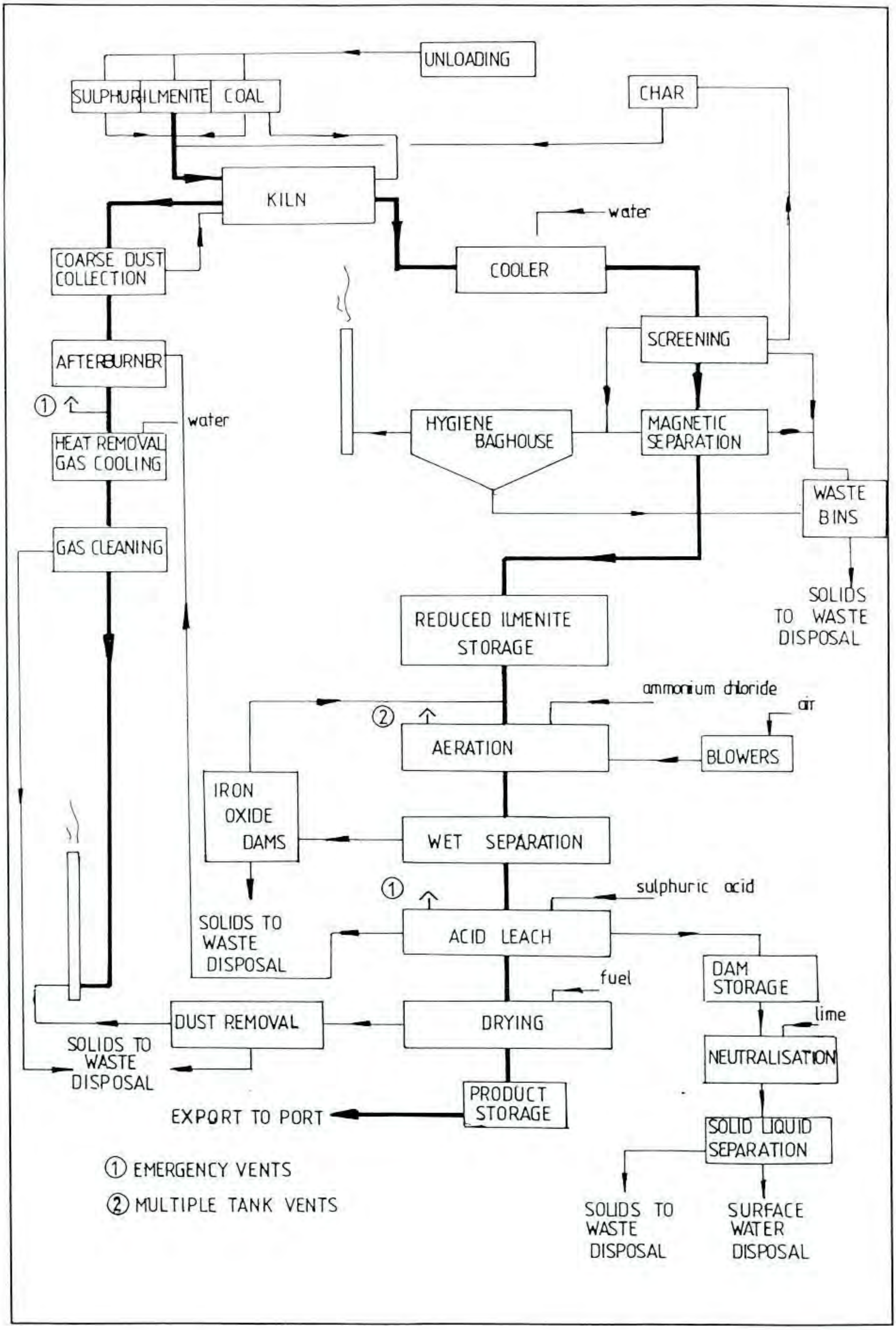

Figure 5.4: Synthetic Rutile Expansion Process Flow Diagram

TABLE 5.1

ITEM	HEIGHT m.	SO_2 g/s	DUST g/Nm^3 dry	H_2S mg/s	TEMP °C.	VOLUME Nm^3/hr dry	FREQUENCY
Main Stack[1]	110	215	<0.3	12	110	120,000	Continuous
After Burner Emergency Stack	38	111	14	6	850	55,000	Occasional[2]
Hygiene Baghouse Stack	40	Nil	<0.25	Nil	15-30	115,000	Continuous
Aeration Tank Vents. Per Vent. 10 off.	25	Nil	<0.25	Nil	~60	4000-7000	Continuous
Acid Leach Emergency Vent	27	Nil	<0.25	40,000	35-45	19,000	Occasional[3]

1. Combined stack servicing new kiln, old kiln and new drier.

2. Emergency stack used only for power outages or water supply problems. Opened also during annual shutdown and start ups at lower volumes and lower pollutants.

3. Emergency vent used in power outage or equipment failure. On emergency acid addition stops and level of pollutants falls quickly.

Reduction

The ilmenite, together with coal, sulphur and recycled char, is heated to 1150°C within a rotary kiln 90m long by 5.0m internal diameter. The kiln is lined with special duty refractory concrete.

Combustion is controlled by sealing the operation from the outside atmosphere and by controlling the input of air along the length of the kiln.

During the reduction process metallic iron is formed within the altered ilmenite mineral grain structure. The products of the reduction kiln are reduced ilmenite, char and coal ash.

The product stream is indirectly cooled to between 80°C and 120°C by passing it through a second unlined steel rotary kiln over which cool water is circulated. This water is recycled after passing through a cooling tower.

Waste Gas Treatment

Gases produced in the kiln pass through four stages of processing:-

- Coarse dust collection
- Afterburning

- Cooling
- Dedusting

Immediately after the kiln, gases pass to a dust settling chamber. This is a refractory lined chamber of large cross section which allows the gas velocity to reduce so that larger entrained particles will drop out. Material is collected in hoppers at the base of the chamber and is continuously returned to the kiln feed system.

The gases then sweep into a large, vertical, lined duct called the after-burning chamber Here, ventilation air from a latter part of the process, acid leaching, is blown at high velocity into the after-burning chamber. The ventilation air will contain small quantities of hydrogen and hydrogen sulphide from the acid leach process. Temperatures in the after-burning chamber are such that coal volatiles, hydrogen and hydrogen sulphide will combust spontaneously with the ventilation air to produce water vapour, carbon dioxide and sulphur dioxide. The process will usually sustain the temperature required for combustion but should that not be so, a fuel burner is provided to support combustion.

Provision is made for direct discharge to the atmosphere after the after-burning chamber. Experience with the existing plant has isolated the need to use this facility to major plant shutdowns, startups and equipment or power failure.

The duration of direct afterburner emissions will usually be brief (less than 5 minutes). Longer openings will only be with the kiln on hold, that is, feed stopped and combustion air input reduced to minimum levels. Under these conditions, emissions are greatly reduced.

The hot gas exiting the after-burning chamber is at 900°C - 1,000°C and contains a lot of energy. The temperature will be reduced before gas cleaning. This section is still under investigation but will include one or a combination of the following:

(a) Direct cooling by injection of water.

(b) Preheating of air for product drying by a gas/air recuperator.

(c) Extracting heat to dry kiln input materials.

(d) Raising steam through indirect heating of water in a boiler. Steam may be used for heating or driving turbine equipment.

Following the cooling and heat recovery stage, fine dust is removed in an electrostatic precipitator. This method of dry gas cleaning was chosen in preference to wet scrubbing to reduce the demand on local aquifers. The electrostatic precipitator also offers advantages in removal of very fine dust particles more efficiently than scrubbing units.

Waste gases from the kiln waste gas system are then mixed with discharges from the existing kiln and the drying waste gases and discharged through a stack of sufficient height to ensure acceptable ground impacts.

Dry Separation

The mixture of solid products from the reduction stage is separated into its major components. Reduced ilmenite is separated from char and other products by screening and magnetic separation. The coarse char separated at the screens is recycled to the kiln to optimise use of fuel. Reduced ilmenite, which is magnetic, is separated from fine char and ash by magnetic separation. Coarse agglomerated particles are removed for further treatment.

The fine dusty materials handled in this area are a potential source of plant dust. All conveyors will be covered to shield material from the wind. All transfer points and equipment will be ventilated to a baghouse where the air is filtered of dust before discharge via a short stack. Dust levels exiting the stack will be normally less than 100 mg/m^3.

Solid waste from the separation and dust collector circuits is stored in plant bins and returned daily to the disposal area for burial.

Oxidation and Separation

The reduced ilmenite undergoes an accelerated corrosion (rusting) process in the aeration section.

The process is conducted in large covered tanks where recycled process liquor, water, ammonium chloride and reduced ilmenite are stirred and blown with air. Oxygen from the air reacts with the metallic iron in the reduced ilmenite to form fine particles of iron oxide separate from the reduced ilmenite particles. Ammonium chloride acts as a catalyst to speed up the reaction.

After aeration (11 hours), a slurry of process liquor, low grade synthetic rutile and iron oxides is discharged to the wet separation section. Hydrocyclones and classifiers separate coarser grained low grade synthetic rutile from the fine grained iron oxide particles. At the same time ammonium chloride solution is washed from the synthetic rutile.

The iron oxide slurry is passed to one of seven lined storage dams where the iron oxide solid settles and the ammonium chloride solution (process liquor) is decanted and recycled to the aerators. The dams are operated in a rotation of fill, dry and empty. The iron oxide is removed to the disposal area for burial or used as a soil conditioner during land rehabilitation. There is a limited market for iron oxides which takes some of the material.

Acid Leaching

The low grade synthetic rutile is passed to the acid leaching section where dilute sulphuric acid is used to dissolve remaining metallic iron and some manganese. After leaching, the slurry is filtered and washed with water to remove the acid.

The acidic leach liquor is processed in the neutralisation plant described later.

Hydrogen and hydrogen sulphide gas generated from the leaching process is directed to the kiln afterburner where it is burnt to produce sulphur dioxide and water.

A fan and vent is provided for the emergency exhausting of leach plant gases in power failure or when sudden interruptions to afterburner processing occur.

Emergency venting will initiate procedures to immediately shut down the acid addition to the leaching process which causes pollutant levels to drop quickly.

Synthetic Rutile Drying

Wet synthetic rutile is dried and then stored in a closed silo, awaiting transport to customers.

The drying operation requires the burning of fuel or extraction of heat from the kiln gas and consequent contact with synthetic rutile to evaporate the water. Gases generated are transported to the kiln waste gas stream and pass out the main stack.

Neutralisation

Acidic leach liquors are blended with those from the existing plant and neutralised by a two stage neutralisation process using limestone followed by hydrated and slurried quicklime.

Acid effluent is mixed with ground limestone to neutralise free acid and bring the pH up to 5.

Complete neutralisation is achieved by adding lime slurry to raise the pH to 10. During the neutralisation process, iron and manganese precipitate as stable oxyhydroxides along with gypsum from the lime.

5.3.2 Alternative Process

The alternative technology under development by Westralian Sands is related only to the portion of the process that removes iron and manganese from the reduced ilmenite and subsequent handling of waste.

Main stages of the process are as follows:

- Reduction of iron oxide in ilmenite to metallic iron.
- Treatment of waste gases from the kiln.
- Separation of kiln discharge materials.
- Oxidation of the iron to form new but physically separate iron oxide particles.
- Synthetic rutile product drying.
- Acidic waste neutralisation.

The shaded steps are performed in a similar manner to the traditional process. A flow sheet of the process is given in Figure 5.5.

The reduced ilmenite is subjected to increased oxidation rates which are significantly above those obtained by the aeration and acid leach stages of the Becher process. This is achieved by the combined use of raised pressure (10 bar to 20 bar), raised temperature (100°C to 200°C) and raised oxygen concentration levels. The oxidation process is conducted in the presence of small quantities of sulphuric acid. The reaction of sulphuric acid with the metallic iron in reduced ilmenite will result in the evolution of some quantities of hydrogen and hydrogen sulphide gases.

In the first phase of processing, small quantities of acid are reacted with fresh reduced ilmenite in a conditioning tank. This reaction will produce hydrogen and hydrogen sulphide so the off–gas from this vessel would be ducted to the after–burning chamber as is the practise in the Becher process. The same precautions and handling procedures would be utilised.

In the pressure vessels, more hydrogen is evolved and as such the reactor area is zone classified with access to the area during operation prohibited and separation of the area from the remaining plant achieved by a full height concrete blast wall to cause any explosive event to vent vertically upwards. The amount of hydrogen generated is monitored and the plant controlled to maintain safe levels of hydrogen concentration. The hydrogen is vented from the reactors and diluted with air and steam to well below the lower limit for flammability and exhausted to atmosphere.

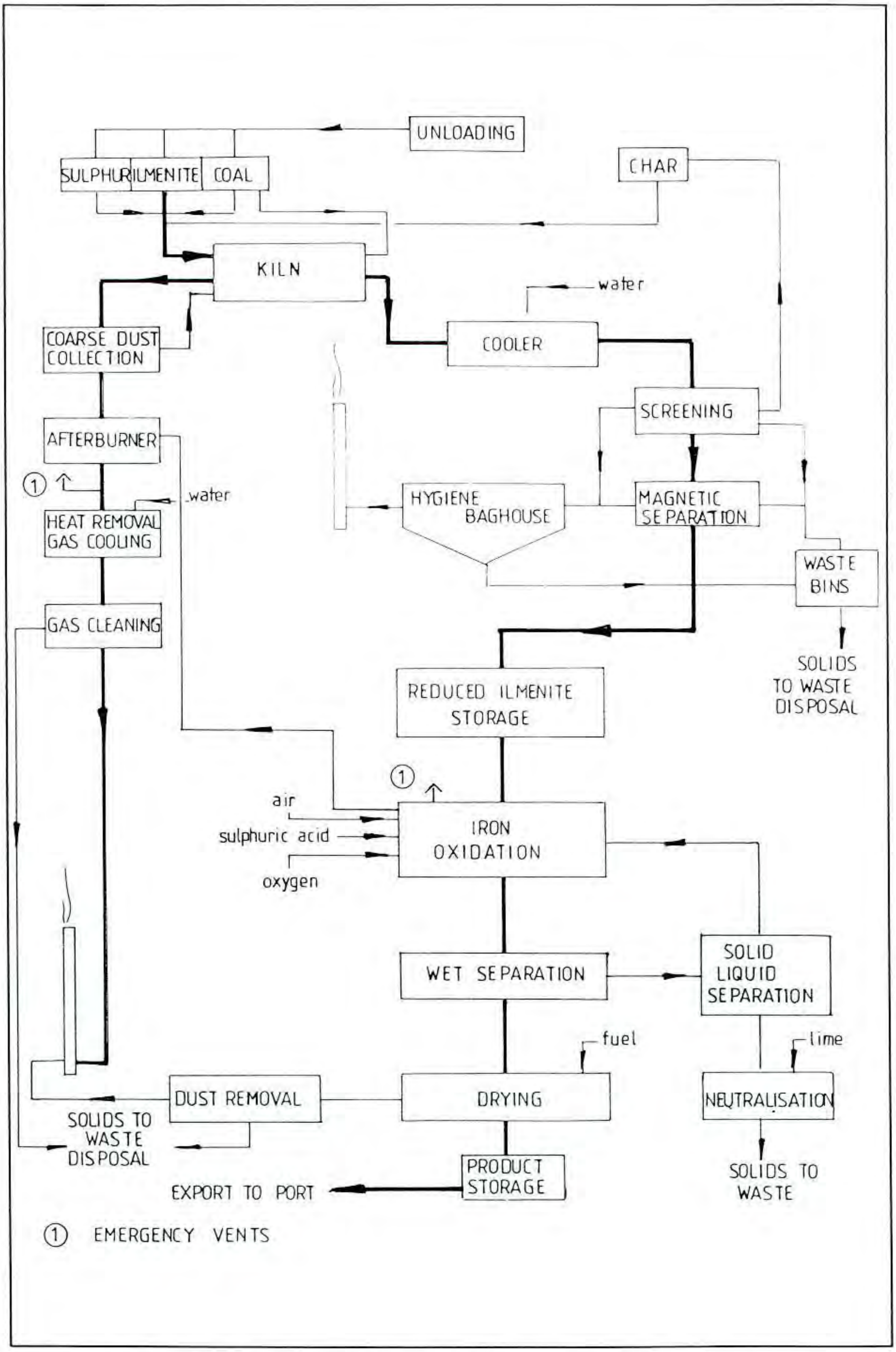

Figure 5.5: Synthetic Rutile Expansion Process Flow Diagram - Alternative Process

The new technology will produce a synthetic rutile suitable for washing and final drying and an iron oxide filter cake containing low levels of dilute sulphuric acid. The iron oxide filter cake will be blended with quicklime to neutralise any residual acidification prior to disposal as land fill with the existing plant solid residues.

5.4 LIQUID AND SOLID WASTE HANDLING

There are several liquid and solid streams which exit the process as waste. All materials in this category are being examined to determine other uses with the aim of minimising total waste from the process.

Liquid Effluent

There will be only one extra source of liquid effluent from the extended plant. Liquor from acid leach (or the new process) will be collected together with liquor from the existing plant and will be neutralised. The neutralised liquor will join the existing scrubber liquor effluent stream. There will be minor discharges of water from cooling towers or steam systems.

The water quality discharged from the expanded site will meet guidelines for drinking water[6] for all health related inorganic chemicals with the exception of nitrate. (See Table 5.2).

TABLE 5.2

GUIDELINE LEVELS FOR HEALTH RELATED INORGANIC CHEMICALS

CHARACTERISTIC	GUIDELINE VALUE Milligram/Litre	CURRENTLY MEASURED VALUE
Arsenic	0.05	<0.005
Cadmium	0.005	<0.01*
Chromium	0.05	<0.01*
Cyanide	0.1	<0.2*
Fluoride	0.5 to 1.7	Not measured.
Lead	0.05	<0.05*
Mercury	0.001	Not measured.
Nitrate	10	About 10**
Selenium	0.01	Not measured.

* Detection limits on equipment used for routine testing.
** The nitrate "level is determined by health criteria for infants under one year of age who are most at risk".

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[6] **National Health and Medical Research Council, Australian Water Resource Council, 1987, Guidelines for Drinking Water Quality in Australia, Australian Government Publishing Service.**

The guidelines also indicate levels for non health related characteristics in drinking water.

These characteristics have an impact on drinking water by affecting the taste or promoting staining of material that the water contacts. (The common red orange staining associated with iron in water is a typical example.)

TABLE 5.3

GUIDELINE LEVELS FOR INORGANIC CHEMICALS - NOT DIRECTLY HEALTH RELATED

CHARACTERISTIC	GUIDELINE VALUE Milligram/Litre	EXPECTED VALUE
Aluminium	0.2	Not measured.
Chloride	400	200
Copper	1	<0.01
Hardness	500	Not measured.
Iron	0.3	0.3
Manganese	0.1	0.5
Sodium	300	100
Sulphate	400	500
Total Dissolved Solids	1,000	1,300
Zinc	5	0.01

NOTE: These parameters will be covered by WAWA licensing.

Process Liquors

Liquor is used in the process to transport the mineral and to provide a chemical environment to extract impurities. The liquors used would be harmful if released to the environment and special precautions are proposed for their containment.

Liquors of concern are ammonium chloride liquor (traditional process only) and acidic liquor. Both liquors contain high levels of dissolved salts and would seriously impact the quality of surface water or ground water in the area if released.

The liquors are transported in pipes overland to dams where they are stored for reuse or treatment. The ammonium chloride liquor is reused in the process while the acidic liquor is recycled before being neutralised and joining other streams to form the discharge water stream. Typical analyses of the liquors is given in Table 5.4.

Acidic liquor, after treatment with lime, is neutralised. The neutralised liquor is moderately saline and does not pose the same risk as either the acidic liquor or the ammonium chloride liquor. The neutralised liquor is mixed with other waste water flows and exits the site via vegetation lined waterways before release into the Elgin Drain.

TABLE 5.4

TYPICAL SALINE PROCESS LIQUORS

CHARACTERISTIC	ACIDIC LIQUOR	NEUTRALISED LIQUOR	AMMONIUM CHLORIDE LIQUOR
TDS	30,000	3,000	25,000
Cl	–	600	10,000
SO_4	20,000	2,000	200
Fe	5,000	2	–
Mn	1,500	0.5	–
pH	1	10	6.8

(All units mg/l except pH.)

Figure 5.3a shows the extent of extra dam construction. The acidic and ammonium chloride liquors will be stored in double lined dams. The liquor itself will be contained directly in a plastic membrane lined dam which will be constructed on top of a second membrane of clay or artificial material. The second membrane will be shaped to direct leaked material to a collection and monitoring point. Figure 5.6 shows the construction of a secure dam system. Neutralised liquor will be contained in a single lined dam. Recommended liner materials are presented in Table 5.5

TABLE 5.5

LINING SYSTEMS FOR DAMS

		PRIMARY	SECONDARY
Iron Oxide	Walls Floor	0.91mm Hypalon 1.02mm PVC	0.51mm PVC 0.51mm PVC
Acid Liquor	Walls Floor	2.5mm HDPE 2.5mm HDPE	0.51mm PVC 0.51mm PVC
Neutralised Liquor	Walls Floor	2.5mm HDPE 2.5mm HDPE	No liner No Liner

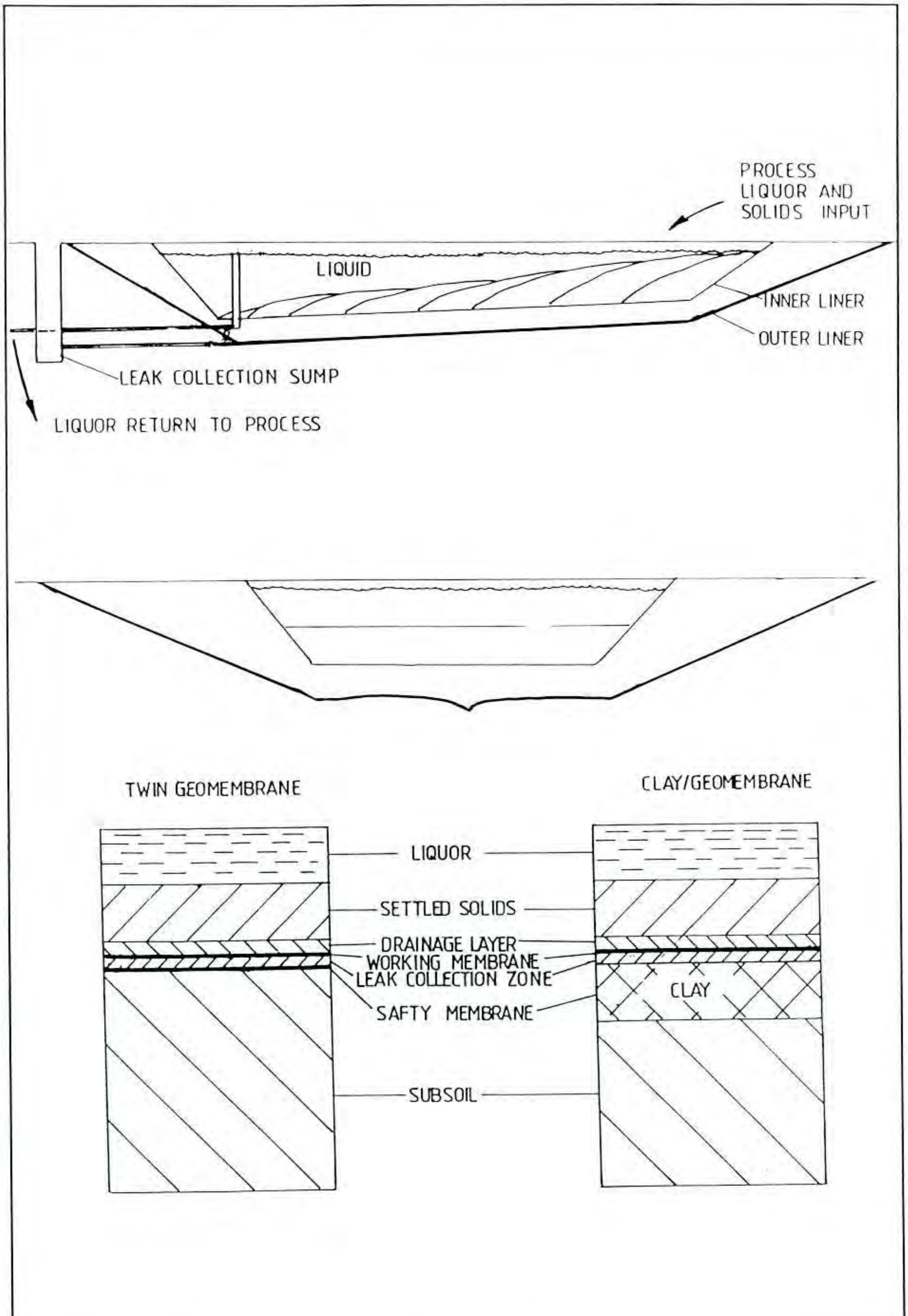

Figure 5.6: Double Layer Dam Liner Arrangement

Once neutralised and solids settled out, the water does not pose a risk to the environment. Treated water is retained in single liner dams.

The use of an artificial wetland to clean liquor was installed and proved successful in the existing plant. The existing wetland will remain and a larger wetland will be established to the south of the plant to supplement it.

In spite of precautions taken to protect the ground water, unplanned events may occur. The network of bores existing to allow sampling and monitoring of ground water will be expanded to service the extended site. Figure 5.7 shows the extent of the existing and proposed borefield on the plant site. Similar bores are in place to service the North Capel disposal site and are shown later in Figure 7.2.

Solid Wastes

Solid wastes originate in four parts of the process. See Table 5.6.

TABLE 5.6

SOLID WASTE PRODUCTS

SOURCE OF WASTE	WASTE MATERIAL	EXISTING AMOUNT t/a (dry)	EXPANDED AMOUNT	
			BECHER t/a (dry)	NEW t/a (dry)
Kiln Product Separation	Lumps Char Inert Solids	11,000 6,000 15,000	24,000 13,000 32,000	24,000 13,000 32,000
Aeration (Oxidation)	Iron Oxides	65,000	140,000	140,000
Neutralisation	Neutralised Solids	20,000	50,000	25,000
Kiln Dust	Scrubber Solids Precipitator Solids	13,000 -	13,000 16,000	13,000 16,000

Iron oxides are recovered damp from dams after settling from ammonium chloride liquor. In the new process, the iron oxides are recovered as a filter cake and are mixed with quick lime to neutralise the contained acidic liquor. The material is very fine and presents a low environmental risk. A small quantity finds a market as fertiliser additive, water treatment chemical or cement additive. The rest is placed in the adjacent disposal pit. The composition of iron oxides is shown in Table 5.7.

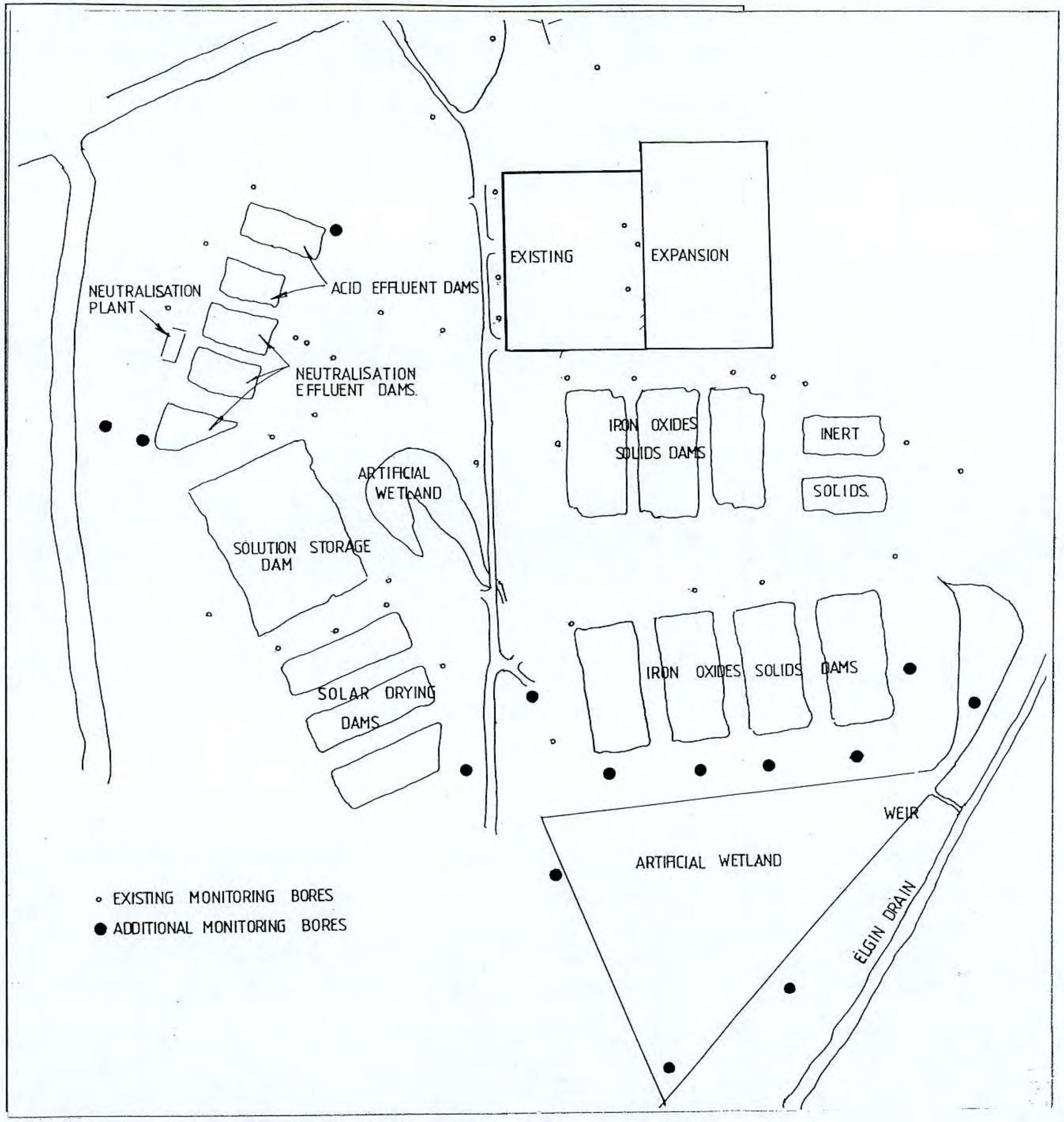

Figure 5.7: Expanded Ground Water Monitoring and Recovery System

TABLE 5.7

TYPICAL ANALYSES - IRON OXIDE SOLIDS

CHARACTERISTIC	ANALYSIS	CHARACTERISTIC	ANALYSIS
Fe as Fe_3O_4	93%	Zn	0.01%
MnO	0.5–1.0%	Sr	0.003%
TiO_2	0.5–5.0%	Cu	0.006%
Al_2O_3	0.4%	Sn	0.008%
SiO_2	0.3%	CO	0.25%
MgO	0.07%	V_2O_5	0.08%
CaO	0.02%	Pb	75 ppm
Cr_2O_3	0.1%	As	40 ppm
ZrO_2	0.01%	ThO_2	50 ppm
Ni	10 ppm	U_3O_8	5 ppm
pH	7		

Neutralised effluent solids are recovered damp from dams. The material is very fine. Test work at the University of Western Australia has shown the material to be a potent absorber of nutrients when mixed into poor sandy soils. The material may have significant benefit in intercepting fertiliser run–off and preventing nutrient build up in ground water and coastal estuaries. Development is progressing on a programme to demonstrate this application. Excess solids are pumped to unlined evaporation ponds from which they are excavated and placed in the disposal pit. The composition of neutralised solids is shown in Table 5.8.

TABLE 5.8

TYPICAL ANALYSES - NEUTRALISED SOLIDS

CHARACTERISTIC	ANALYSIS	CHARACTERISTIC	ANALYSIS
Fe as FeOOH	7–15%	Zn	60 ppm
MnO	0.7%	Sr	0.2%
TiO_2	1–2%	Cu	65 ppm
Al_2O_3	0.3%	Sn	90 ppm
SiO_2	5%	Pb	70 ppm
MgO	0.8%	V_2O_5	<0.01%
CaO	24%	ThO_2	0.03%
Cr_2O_3	<0.01%	SO_4	30%
ZrO_2	0.04%	LOI*	47%
Ni	30 ppm		
pH	10		

*LOI – Loss on Ignition represents sulphates and carbonates which decompose on heating.

Dust removed from the kiln off-gas will be variable in composition but will consist of fine coal char, fine ilmenite and fly ash. It is likely that ilmenite will be extracted. The remaining solids will be dampened to prevent dusting and placed in the disposal pit.

The wastes from the kiln product separation area have high potential for recycling. Carbon bearing materials may be used as a cheap solid fuel and lumps may be crushed and reused. Any solids remaining as waste will be dampened and placed in the disposal pit.

The North Capel mine pit is adjacent to and north of the plant. It is used as the disposal site for solid waste. Wastes are transported to the pit by truck. No trucks will enter public roads en route to the disposal site. It is projected that the life of this site will be between 7 and 15 years.

5.5 EQUIPMENT NOISE

Equipment in the extension will be quieter than in the existing installation. Aeration blowers will be of a centrifugal type. These will not present the vibrations generated from the current Rootes type blowers. Fan motors and vibrating equipment will be specified for noise levels lower than equipment now in service.

Westralian Sands commissioned consultants Herring Storer Acoustics to undertake a study of the likely noise emission from the proposed expansion.

The Environmental Noise Model computer programme was used to determine noise propagation based on input including:-

- sound power levels of existing plant
- file data of a modern synthetic rutile plant
- surrounding topography, and,
- atmospheric conditions.

Sound level contours were generated for the existing plant, extension alone and the expanded plant. Predictions were also made for the expanded plant under adverse wind conditions. (See the report in Appendix 4 and Appendix 5.)

The nearest residences are to the northeast of the plant along Cable Mine Road and to the west near Bussell Highway.

The current policy of the EPA is to standardise on levels of 40 dBA at night, 45 dBA in the evening and day time on weekends and public holidays and 50 dBA during working days. These limits are required where the industrial source is the predominant noise (5 dBA above background).

To the west of the site, noise of traffic on the Bussell Highway often masks attempts to monitor plant noise. The much higher levels of noise 'carried' by 3 - 4.5m/s winds will also be masked to some extent by noise generated by the wind.

Predictive noise modelling indicates the proposed plant will generate approximately 10 dBA less than the existing plant. No additive effect is expected. Resultant levels of the combined plant will be 42 dBA at the nearest residential locations under calm conditions.

Under adverse conditions (breeze at 3 - 4.5m/s) the generated noise may exceed 50 dBA. Under these conditions, wind noise will also be significant. Appendix 5 examines the frequency of adverse conditions on nearby residences.

5.6 PLANT SERVICES

Water Supply

Water requirements for the process are to be met from bores into the Yarragadee Formation. Currently 5 production bores (licensed by WAWA) provide approximately 2.7 million m3 of water per annum to service the existing synthetic rutile plant, North Capel dry plant, associated infrastructure and land rehabilitation.

A deep bore of 150 to 250 metres will be constructed to supplement supply. An existing bore will be relocated. The proposed expansion will require an additional 2 million cubic metres of water per annum. The additional quantity depends on the form of waste recovery incorporated and represents the maximum requirement for any options. A typical balance for water usage and discharge is presented in Figure 5.8.

Water quality is not suitable for direct use. Water treatment facilities will be expanded to aerate and filter the water and, if required, sterilise and adjust the pH.

Power Supply

Electrical power is supplied to the site by SECWA through a 66 kV high voltage line. The existing 10MW capacity is adequate to service the anticipated demand from the expanded site.

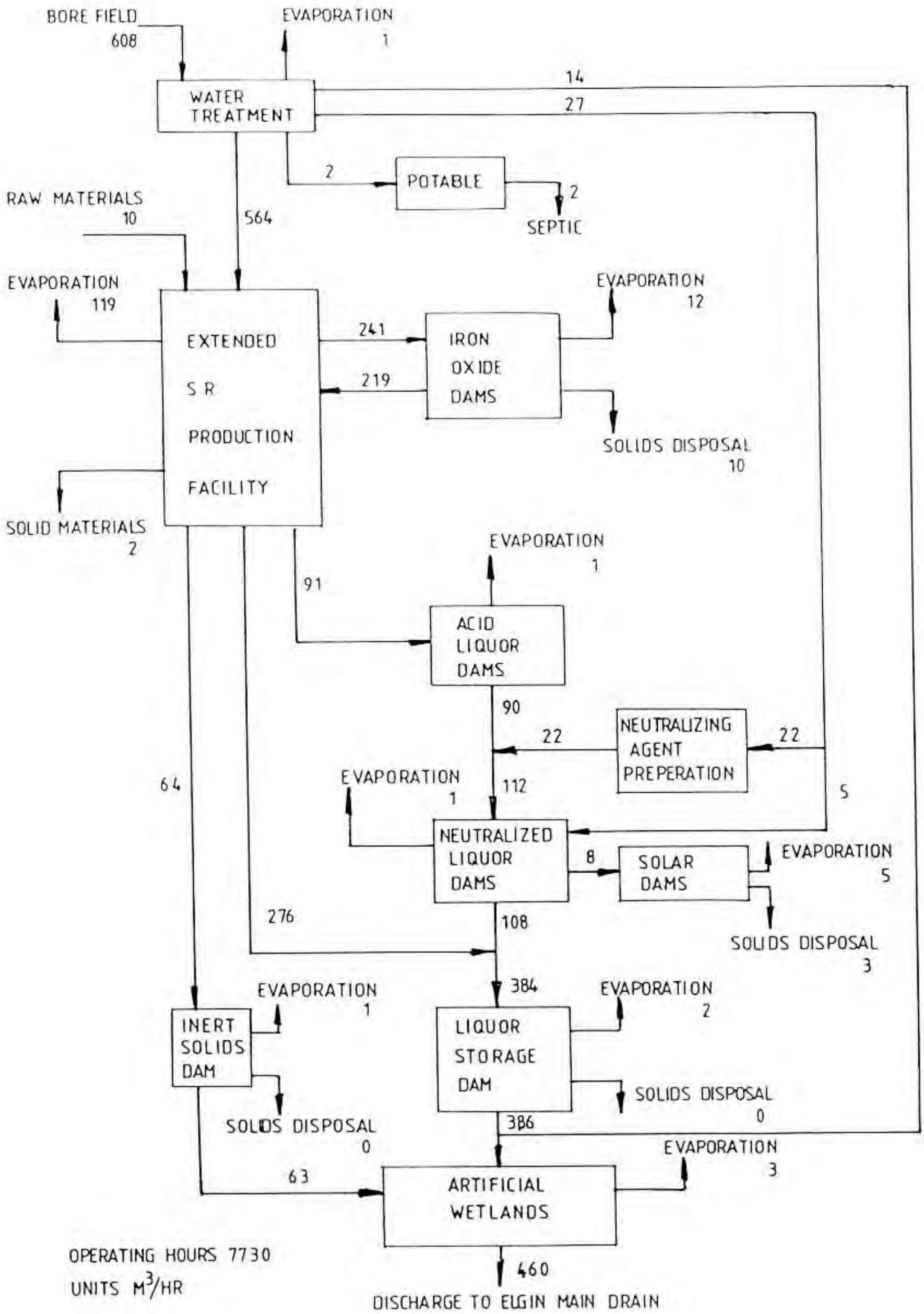

Figure 5.8: Water Balance for Proposed Expansion. Maximum Water Demand.

Air Supply

Compressed air that is used for process control instrumentation will be generated on site by blowers and compressors. It will be reticulated to the required locations.

Process Control and Instrumentation

The proposed plant will incorporate modern logic based process control and instrumentation. The plant will be continuously monitored in a central control room.

Particular attention will be paid to ensure that the operation of plant machinery is continuously monitored and controlled to set the operating parameters, determine operating performance and detect deviation from the required condition.

Deviation from desired operating performance will result in alarms being activated in the central control room. Control room operators will be experienced and highly trained people who are familiar with the plant and its systems. They have access to direct intervention through the instrumentation or through radio contact with plant operators. The alarm notification will necessitate attendance by the operator to resolve the deviation.

The extent of automation will be appropriate to ensure that the environmental, safety and production objectives of the company, the EPA and the community at large are maintained at the best practical standards.

Natural Gas and Fuel Oil

Fuel oil is supplied to the site by road tankers for the existing operations. A small increase is anticipated after the expansion to service the increase in mobile equipment.

Gas requirement to operate burners for heat generation will be supplied by LPG or natural gas depending on the commercial negotiations underway. Depending on the outcomes of these negotiations the supply will be by direct pipeline from an extension of the existing line south of Bunbury or by road tanker to on-site storage facilities. These facilities will be in accordance with all required safety standards. On site storage of LPG will be in an area in the northern part of the expanded plant and will hold up to 50 tonnes of gas.

Mobile Equipment

The following mobile equipment is to be purchased to support this proposal:-

3 service vehicles.

1 large rigid body truck.

5.7 WORKFORCE

Construction Workforce

An average of 100 persons will be employed on site over a 2 year period. The construction workforce is expected to peak at approximately 200 persons and follow a pattern as shown in Fig 5.1.

It is expected that an existing pool of local labour will be supplemented by workers commuting from Perth/Kwinana. Construction firms will be encouraged by the proponent to employ locally where possible.

Details of accommodation for the construction workforce will be determined by the contractors to the project in close consultation with the proponent and local authorities. Should a construction camp be set up, a management plan will be drawn up to the satisfaction of the Shire of Capel and the EPA. Temporary accommodation in caravans is a possible option. Six caravan parks exist in the Capel/Greater Bunbury area.

Construction work will usually be carried out in daylight hours.

Operational Workforce

Fifty permanent jobs will be created by the plant expansion. Approximately 30% of these would be available to unskilled/semi-skilled applicants with the balance being filled by skilled workers and tradespeople. The permanent workforce is expected to follow the existing pattern which indicates that almost all new employees will be recruited locally.

An ongoing training and education programme is currently available for skilled and unskilled employees. This programme, which includes familiarisation with environmental impacts, will be further developed and presented to new employees.

The plant will operate on a continuous basis. Approximately 25 of the extra employees will work shifts. Employee traffic will be generated on neighbouring roads three times per day. Car pooling is popular and little impact is expected on road traffic.

5.8 DECOMMISSIONING AND REHABILITATION

Rehabilitation commitments will be consistent with those made for the existing operations in the Public Environmental Report and the company's Final Submission to the EPA included in Bulletin 225.

These are summarised below:

Upon final plant closure, all sections of the plant will be dismantled and removed off site.

All effluent ponds will be drained of liquid. Any water discharged will be treated to ensure compliance with EPA/WAWA standards. Aeration liquor (containing ammonium chloride) will be solar evaporated and dissolved salts recovered.

All solid wastes will be disposed of into surface pits. Pits will be capped with clay to prevent rainwater derived leachate. Solids with greater potential to pollute underground water (for example, ammonium chloride and metalliferous sludge from the biological filter) will be placed in clay–lined, engineered disposal pits and capped with clay.

All ponds and other excavations will be infilled with clean sand. Land will be recontoured, topsoil laid down and replanted to pasture species.

Monitoring of leachates will continue for a minimum of two years should earlier monitoring indicate this is necessary. After this period of time, monitoring will be continued until the degree of leachate generation is determined. Management strategies will aim to prevent leachates being generated.

Records will be maintained detailing the history of site activities and noting locations of all areas of solid disposal.

6. PUBLIC CONSULTATION

6.1 COMMUNITY CONSULTATION

A community consultation programme has been set up to encourage the community to understand and contribute to the planning and decision-making processes relating to this project. The programme aims to identify areas of concern such that those concerns may be taken into account during the preparation of the CER.

The consultation programme so far has focused on the Capel Shire and has included the following initiatives:

1. ***Synthetic Rutile Plant Announcement***

   At the time a proposal application was submitted to the Department of State Development and referred on to the EPA, a media release was distributed and a briefing organised for the Capel Shire Council.

2. ***Briefings for Community Groups***

   The Capel Industry Liaison Committee - formed to promote and improve communication between local industries and the community - was briefed and provided with a draft project summary.

   The Liaison Committee will provide a forum to canvas and discuss potential community concerns and queries regarding the proposal so that they may be adequately addressed through the EPA Environmental Impact Assessment procedure.

   The Capel Shire Communities Association has been provided with details of the project. A meeting in February was addressed at which members of the group were given the commitment that they will be kept informed and included in the consultation process.

3. ***Briefings for Local Government***

   The Bunbury City Council Planning Committee was briefed and provided with details of the proposal at the January 7 meeting.

   The Collie Shire Council was approached early in the process of project development. The proposal requires coal and associated truck movements through the town of Collie to double. Management of this issue will be resolved in close consultation with the Collie council.

Matters raised in the course of this early consultation process were given particular attention in the preparation of this document.

Following the release of the Consultative Environmental Review the public consultation programme will incorporate the following key elements:

- regular media release and advertising information directed to local newspapers.
- public and private speaking engagements.
- information display to be located at local libraries.
- consultation and negotiation with local shires.

At the release of this document a press statement was released covering the key findings of the review. A summary of the CER was also distributed as a separate document.

6.2 GOVERNMENT LIAISON

Westralian Sands has maintained regular contact with the following government departments:

- Department of State Development
- Environmental Protection Authority
- Social Impact Unit
- Water Authority of Western Australia
- Main Roads Department
- State Energy Commission of WA
- South West Development Authority
- Department of Transport
- Bunbury Port Authority
- Department of Mines

Government officers have been kept up to date with the project development and given the opportunity to tour the existing operations.

Liaison with these organisations will be maintained throughout the planning and commissioning of the plant. This will be incorporated into an ongoing government relations programme effective for the company's existing operations.

The company has been negotiating with the Capel Shire Council over the proposed closure of Yeardy Road. An alterative route has been agreed to and the company is continuing discussions with the Shire to determine the details of this agreement.

7. ENVIRONMENTAL IMPACTS AND MANAGEMENT

7.1 IMPACT DURING CONSTRUCTION

Site preparation for construction will involve clearing some trees, levelling, drainage work and road construction. The land involved is directly adjacent to the existing plant and has undergone significant disturbance previously. (See Section 4.4).

Before clearing operations by bulldozers are carried out, any millable timber will be felled and removed from the site.

The main environmental impact during construction is the potential to generate dust. Management measures will include ensuring the area of land disturbed and left bare is kept to a minimum to ensure fugitive dust emissions do not create a nuisance beyond the company's boundaries.

Any unsurfaced roads that may generate dust during windy weather will be watered as required. This occurs as a matter of course for the existing operations.

Commitment:

- ***The generation of dust as a result of construction activities will be managed by:***
  - ***ensuring areas disturbed and left bare are kept to a minimum***
  - ***keeping unsurfaced roads dampened.***

7.2 IMPACT ON WATER RESOURCES

7.2.1 Ground Water Consumption

Water is drawn from deep aquifers of the Yarragadee Formation to service the North Capel processing plants, associated infrastructure and land rehabilitation.

The plant expansion will require up to 2 million cubic metres per annum of water in addition to the 2.7 million cubic metres per annum currently extracted.

Total water resources in the Busselton, Capel ground water area are estimated to be 82 million m^3/year of which only 13% is committed.[7] Within the Capel area, access to a portion of this reserve is available. Water is drawn from a number of bores in the area and the local capacity of the aquifer needs investigation.

A study was commissioned by the company to investigate the state of the aquifer and the impact of the current operations on the ground water level. Evidence suggested a

[7] Water Authority of Western Australia, July 1990, Overview of Ground Water Resources of the South West Region July 1990, Report No.WG112.

significant increase in water demand for the synthetic rutile plant expansion could be adequately met by the Yarragadee aquifer. A further study (Appendix 3) investigated the demand on the aquifer in the Capel area and concludes:

> "There are sufficient ground water resources available in the Yarragadee Formation to meet the additional process water demand of the SR plant."

Commitments:

- ***After consultation with EPA and WAWA, the existing monitoring programmes will be expanded to collect data for a regular review of aquifer performance.***

- ***The company will maintain ongoing liaison and consultation with the EPA and Water Authority of WA with respect to aquifer performance.***

- ***Water consumption will be minimised through recycling, dry scrubbing of gases and re-using saline water at appropriate locations.***

- ***Should other demands on the aquifer compound to have a detrimental impact, the company will review with WAWA ways to reduce its impact on ground water supply.***

7.2.2 Surface Water Discharge

All surface water discharged from site will meet licence conditions as determined by the WAWA and the EPA. Discharge water quality will be as detailed in Table 5.2 and 5.3.

Discharge volume will be increased by up to 65% reflecting the increase in water extraction. The discharge will supplement the existing flow to the Elgin Drain.

Consequences of the discharge include a year round flow of water through the Elgin Drain which had previously dried up to stagnant pools in summer. Farmers further downstream may use the water for irrigation of their properties thereby avoiding having to use their own bores for agricultural purposes.

Commitments:

- ***A controlled monitoring point consistent with WAWA standards will be established prior to discharge into the Elgin Drain.***

- ***The surface water discharge will be maintained at the licensed quality and quantity specified by the WAWA.***

- ***Monitoring will be conducted as in Table 8.1. Results will be collated and a report submitted to the WAWA on a regular basis as requested.***

- ***The company will ensure that ongoing discussions are maintained with WAWA to develop improvements in the surface water discharge.***

- ***Should monitoring detect breaches of the discharge criteria set by WAWA then the source of the deviation will be identified and corrective action promptly taken. If this requires operations to be shut down, then that action will be taken.***

7.2.3 Site Run-off

The plant area will be bounded by a system of drains which will divert all run-off into a wetland before discharge into the Elgin Drain (Figure 7.1). The point of discharge is closely monitored to meet WAWA and EPA licence conditions.

Management strategies to ensure surface waters remain free of contamination include:

- bunding or covering of potential sources of contamination.
- secondary containment and recovery to pipelines transporting wastes.
- general cleanliness of roadways and open plant areas.

The wetland will provide a final safety net, retaining material within the plant site.

Commitment:

- ***To avoid contamination of surface run-off, the company will:***
  - ***maintain the physical integrity of all bunded and contained areas***
  - ***regularly clean all roadways and open plant areas; and,***
  - ***regularly clean plant drainage ways.***

7.2.4 Ground Water Quality

Ground water quality may be impacted by the following sources:

1. Leakage from containment dams.
2. Leakage from process liquor streams to and from containment dams.
3. Leaching from long term solid waste disposal pit.
4. Spillage from transport and storage of raw materials.
5. Equipment failure spilling process liquor streams.
6. Artificial wetland seepage.

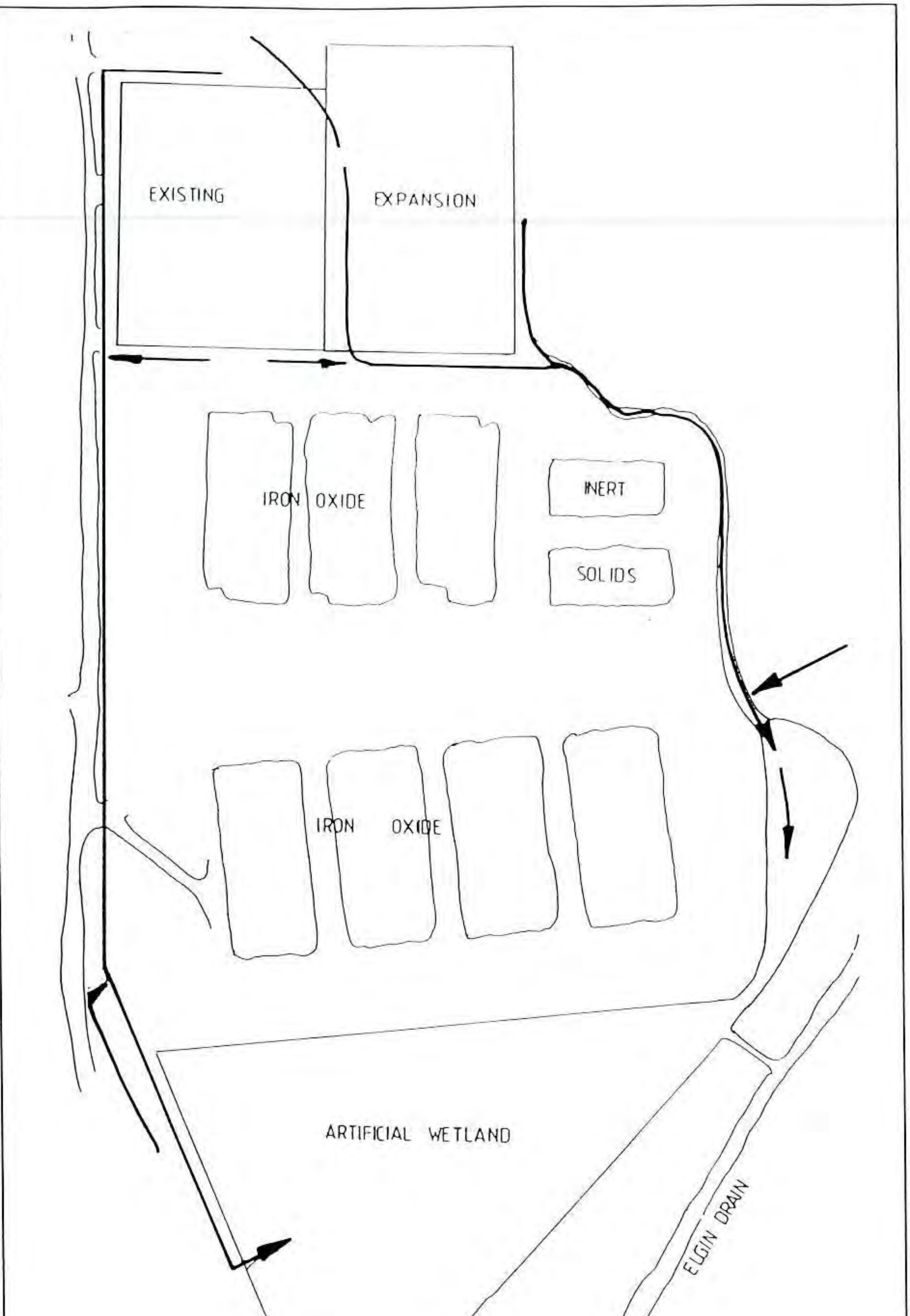

Figure 7.1: Storm Water Run Off

Dam Leakage

High priority dam construction incorporates a leak detection and collection system shown in Figure 5.6 and described in Section 5.

Following the emptying of a dam the liner is examined for tears or other damage. Salinity tests, utilising ground conductivity sensing equipment, may be conducted to determine changes in ground conductivity in the vicinity of the dam. Initial filling is to a depth of 1.5 metres with clean water. Levels are monitored to determine if falls are more than that attributable to evaporation. If a leak is detected, the dam is cleared and repaired before being placed in service.

Commitments:

- ***The company will construct double membrane containment dams to contain acidic and ammonium chloride liquors. The secondary membrane will have the facility to direct leaked material to detection and collection systems.***

- ***The company will maintain strict procedures to check the integrity of primary membranes in dams before being placed in use or returned to use.***

Process Liquor Transport

Overland pipelines will be constructed from high density polyethylene and contained within lined troughs. High integrity fibreglass piping will be used where secondary troughing is impractical or visibility restricted, making inspection difficult. All pipe joints will be visible and accessible.

Spillage will flow into the bunded area and be pumped back into the process. An alarm will alert the control operator who will initiate visual inspection and appropriate repairs.

Commitments:

- ***Overland pipelines of saline or acidic liquor will be run in lined troughs draining to instrumented recovery sumps.***

- ***Where pipelines cannot be treated to secondary containment the pipe will be continuous and will be of a high integrity material.***

- ***Prompt action will be taken to prevent leaks or spills reporting to ground water. Action will include plant shutdown if necessary.***

Solid Waste Disposal Pit

Disposal of solid wastes in the North Capel mine pit will follow the EPA approved methods as outlined in the EPA Report and Recommendations, Bulletin 225, for the existing synthetic rutile plant.

The potential impact on ground water will be from leachate generated from percolation of rain water through the compacted solids or from surface run-off during rain storms.

The company has a management plan in place controlling activities associated with the disposal pit. The plan has been developed to ensure impact on the environment is minimised.

The potential leachate from the solids contained in the waste disposal pit may contain ammonium chloride, manganese, iron and gypsum.

The pit disposal will be controlled to minimise the active dumping zone and to reduce potential run-off.

The solids will be deposited on clean sand at a level greater than 1 metre above the winter water table. The material will be laid down according to the diagram shown in Figure 7.2.

The wet solids are, during dumping, compacted by the earth moving equipment. As the pit fills, the profile is laid down to ensure maximum rain water run off and minimum percolation. As the dumping progresses the surface will be covered with sand and rehabilitated with trees. The trees will have some benefit in evaporating water and slowing the downward movement through the solids. Percolation rate through the compacted solids is very low; comparable to that through clay.

A monitoring system has been installed as part of existing activity and is regularly sampled for salinity and a range of metals. Should deterioration of water quality be observed then action will be taken to prevent further deterioration. If the water quality is significantly altered then recovery and retreatment of ground water will be initiated.

Recovered water will be used for irrigation or will be retreated in the plant depending on the quality and the decision taken in consultation with WAWA officers.

Commitment:

- *Ground water monitoring as agreed with WAWA around the North Capel disposal pit will continue. Action will be taken to identify the source of any*

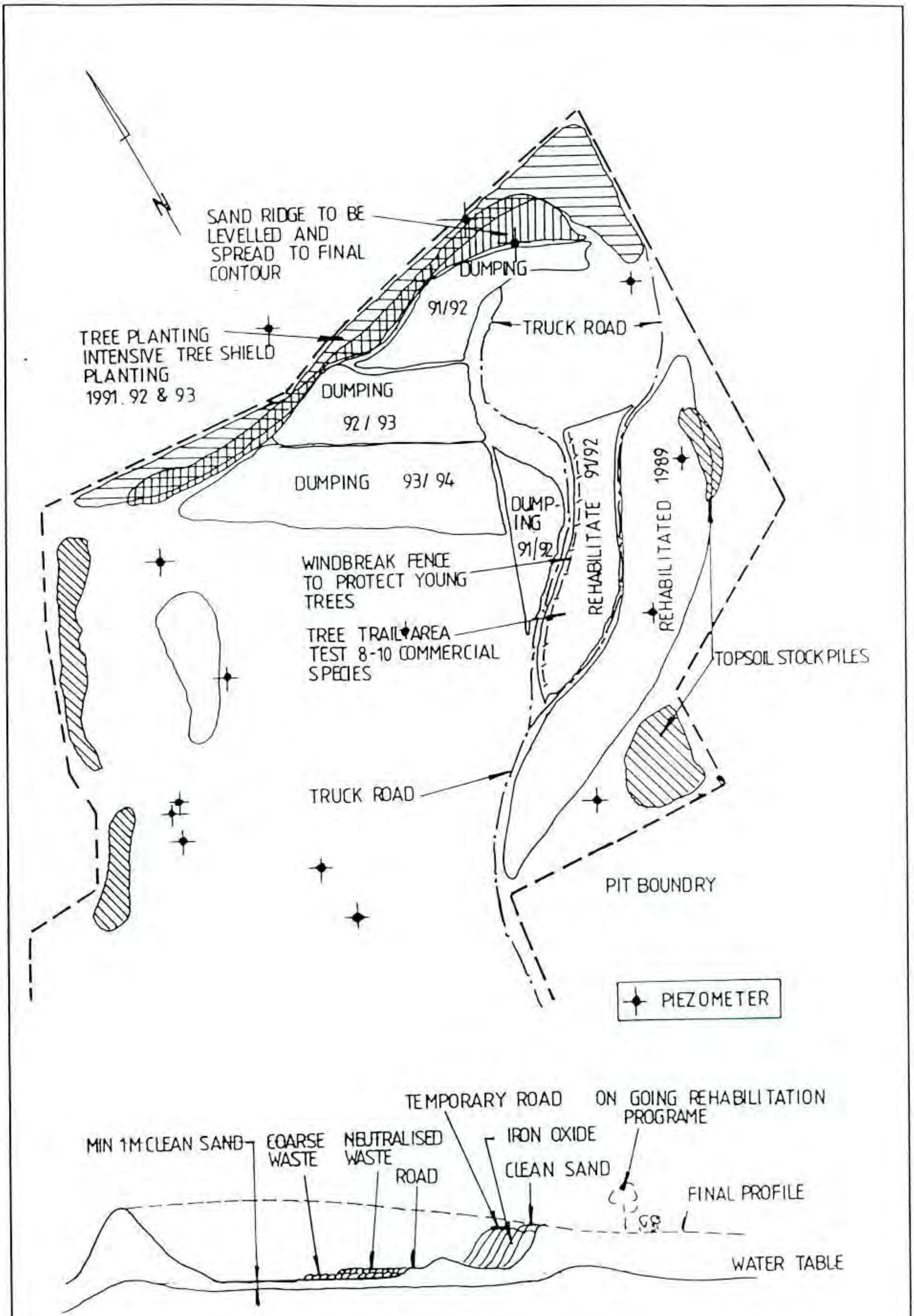

Figure 7.2: North Capel Waste Disposal Site

quality deterioration. Ground water recovery and clay capping are alternatives which may be employed if required.

Material Spillage and Storage

Materials transported around the site are classified according to their potential to impact adversely on the environment.

High Potential:	Sulphuric acid
	Sulphur
	Ammonium chloride
	Quicklime
Medium Potential:	Iron oxide wastes
	Neutralised solids
	Synthetic rutile
	Reduced products
Low Potential:	Ilmenite
	Coal
	Lime sand

Sulphuric acid and quicklime are transported in mild steel road tankers in accordance with regulations for transport of dangerous goods. Sulphur is transported in covered trucks and ammonium chloride is bagged on pallets.

Sulphuric acid will be stored in a mild steel tank contained within a lined bund. The bund will hold the contents of the tank. The transfer station and the standing area for the tanker will be contained and drained to a sump in case of leakage or hose burst during transfer. Containment will accommodate the contents of a tanker. Spilt acid will be neutralised or returned to the plant.

Quicklime will be stored in a silo within the lime plant which is bunded. The transfer area and tanker standing area will be sealed with clay and contoured so that drainage will report to the neutralised effluent dams.

Sulphur will be stored in bunded areas and will be covered in the case of long term storage or will be drained to acid effluent treatment if exposed to the weather. Precautions will be taken during delivery or movement of sulphur to minimise dust or spillage.

Ammonium chloride is handled in bags and stored in a bunded covered area. Spillage from ruptured bags during transfer from transport will be immediately cleaned up.

Medium potential impact materials will be stored under cover or in designated areas in the case of permanent disposal. There will also be a designated intermediate storage area which will be clay surfaced and surrounded with ground water monitoring bores.

Low potential impact materials will be stored in designated areas. Provisions will be made to contain and recover accidental spillage at transfer points. Potential to contaminate ground water will be minimal due to clean up procedures and the nature of the materials.

Remedial action will be taken should incidental contamination of ground water be detected.

Commitments:

- *All materials spilled during transport or transfer will be promptly disposed of in a manner acceptable to the EPA.*

- ***Sulphuric acid will be transported in steel road tankers and transferred to a steel storage vessel in a secondary containment bunded enclosure. The transfer area will be designed to contain spillage during transfer.***

- ***Sulphur and ammonium chloride will be transported in conventional road transport and will be stored under cover on concrete flooring.***

- ***Lime will be transported in a steel road tanker and transferred to a steel storage silo. The transfer point will drain to local effluent pondage.***

Equipment Failure

Liquor processing areas will be fully bunded. Within bunded areas, spillage will drain into sumps and be returned to the process stream. Outside the bunded areas any solid spillage will be swept up and returned to the processing routes or disposed of with solid wastes generated by the process.

Commitments:

- ***Processing equipment and plant pipe runs handling liquids, other than water, will be bunded and serviced by automatically activated recovery sumps.***

- ***In the event of a spill escaping the bunding, soil and ground water will be tested and recovery initiated if required.***

Wetland Seepage

The water entering the wetland will not be significantly different to that which is discharged into the Elgin Drain. Consequently, impact on the ground water will be minimal (see Section 4.6.3).

Monitoring and Recovery

Should spillage or leaching of solids occur, the quality of water in the superficial formations will be impacted. The water in the formations moves to the west and south as described in Section 4.6.2. The company will review and rationalise its system of monitoring bores so that affected ground water will be identified.

If monitoring shows the quality of ground water to be adversely affected, then the water will be recovered and retreated or disposed of in a manner acceptable to the Water Authority.

Recovery is currently performed by identifying the direction and spread of affected water and digging a trench across the flow direction of sufficient length to capture the width of the plume. The trench is then filled with coarse rock or gravel with a soak well in place and a pump is installed to extract the water.

Commitments:

- ***The company will revise its ground water monitoring programme in consultation with WAWA to service the expanded operating site.***

- ***Water quality will be reviewed with WAWA on a regular basis. Water that is adversely affected will be recovered and treated in a manner acceptable to WAWA.***

7.3 IMPACT ON AIR QUALITY

Air quality is impacted through release of process and ventilation gases and through general physical activity in handling and transporting of materials.

The impacts to be managed are sulphur dioxide emissions, particulate (dust) emissions and generation of unpleasant odour.

7.3.1 Sulphur Dioxide

Sulphur dioxide is generated predominantly in the kiln and in the afterburning stage of the waste gas handling system. The SO_2 originates from the addition of sulphur to the ilmenite – this is required to aid in the later removal of manganese. The manganese is an important minor impurity in the processing of pigment. SO_2 in smaller quantities is generated from the burning of coal in the kiln and in drying processes on the site. The proposed SO_2 discharges on the site are given in Table 7.1.

TABLE 7.1

PROPOSED SOURCES OF SO_2 EMISSIONS AT NORTH CAPEL

	MAIN STACK	EXISTING DRIER STACK	NORTH CAPEL DRY PLANT
SO_2 g/s	215	15	2.5
Volume m^3/hr wet	260,000	23,000	28,000
Temperature °C	110	60	60
Height of Discharge m	100	35.5	4.5

Emission of SO_2 is covered by an environmental protection policy consistent with the WHO guidelines mentioned in Section 4.7.1. The limits that have been set are summarised in Table 7.2 and are based on one hour sample periods. The 99.9% compliance refers to an annual period which means that eight exceedances of one hour duration are permitted in one year for that standard.

TABLE 7.2

DRAFT REQUIREMENTS FOR GROUND LEVEL SO_2 IMPACT

DESCRIPTION OF AREA IMPACTED	99.9% COMPLIANCE	NEVER TO BE EXCEEDED
Residential Zone	350	700
Buffer Zone	500	1,000
Industrial Zone	700	1,200

7.3.1.1 Predictions of Impact

The dispersion of SO_2, after discharge to the atmosphere, may be predicted mathematically using weather data, ground topography data and details of the gaseous discharges. The data is analysed using computers and specific programmes. Many mathematical models have been developed to simulate the atmospheric dispersal of gases. This report has used two such models for reference. Weather data has been collected at a site in Glen Iris, east of Bunbury city centre and has been used previously for assessments in the Capel to Kemerton area. Data relating to variation of weather conditions with altitude is also available from the site but the volume of data is limited. An assessment of data collected at Perth airport has been used to identify the frequency of climate variations with altitude which impact on dispersal. A description of the prediction procedures and results along with supporting weather survey is provided in detail in Appendix 6.

Both models predict that the limiting ground level concentration of 700 microgram per cubic metre for residential zone will not be exceeded at any point within or outside the company's boundary.

The AUSPLUME model is widely used throughout Australia for predicting atmospheric dispersion. It has been extensively tested in the Latrobe Valley in Victoria and is used by the EPA for studies in Western Australia. This model analyses weather data for a whole year and predicts concentrations hour by hour on a grid around the emission sources. Figure 7.3 displays the predictions as contours of ground level concentration of SO_2. The contours outline the 9th highest hourly registration for a year (this represents the 99.9% compliance level). Predictions from the AUSPLUME modelling indicates compliance with the EPA's environmental protection policy.

AUSPLUME has limitations in assessing the impact of certain meteorological phenomena. Two such phenomena are 'morning fumigation' and 'thermal convection'. The CSIRO has developed a model for predicting dispersion during such conditions. This model has been applied to data collected at Glen Iris of an event regarded as severe in terms of promoting the impacts described below.

Morning Fumigation: On still, cold, fine mornings the plume from a stack may be contained by a very stable inversion with little dispersion. As the ground temperature rises with solar heating, the air contacting the ground will start to warm and mix with that above. The mixing zone will grow upwards until the inversion is eroded. During this process the layer at which the plume has been constrained may be mixed to ground rapidly at concentrations higher than for normal dispersion.

Thermal Convection: On sunny days where sunshine has heated the ground to a temperature much higher than the general air mass, the air adjacent to the ground becomes warmer and less dense than that above. Under these conditions the warm air may rise rapidly in discrete cells called thermals. The rising thermal is matched by a larger but less vigorous downward movement. This down draught may draw a plume rapidly to ground from a height up to several hundred metres with little chance of dilution.

The CSIRO modelling of these conditions predicts that ground concentrations in the range of 350 - 700 $\mu g/m^3$ will be recorded from 0.7 to 3.5km downwind of the stack. Modelling also predicts that several consecutive exceedances of the 350 $\mu g/m^3$ will be associated with each similarly severe climatic event.

Data used for the CSIRO modelling was obtained at Glen Iris using radiosonde measurements from balloons released at regular intervals. Data of this type is limited from the Bunbury region. It is routinely obtained at airports at Perth and Albany. The Bureau of Meteorology has examined several years of data at Perth and has estimated the frequency of severe inversions which may reproduce conditions similar to those modelled.

The Bureau of Meteorology has estimated the occurrence of 27 major inversions per year at Capel of severity to impact on dispersion though only seven will be of a similar severity to the one used for CSIRO modelling. Generally inversions are associated with northeast to easterly winds. In those directions the plant boundary varies from 1.5 to 3km from the stack.

The occurrence of major inversions is generally related to specific broad synoptic weather systems. These systems are readily recognised and hence the potential for major inversions is predictable.

7.3.1.2 Control Strategy

To ensure compliance with EPA policy, the company will install a continuous monitor to sample and analyse SO_2 in the waste gases exhausting from the main stack. Sulphur additions to the kiln may be adjusted to ensure the analysis does not exceed levels used in the modelling to predict compliance.

The occurrence of conditions promoting severe morning fumigation and convection, though uncommon, is sufficiently frequent to require special management. Broad synoptic features determine the establishment of these unfavourable conditions. The Bureau of Meteorology has offered a service to alert the company to forecasted onset of these unfavourable conditions. The Bureau states that the confidence of prediction is high. Additions of sulphur to the kiln may be curtailed prior to sunrise to minimise impact later in the morning. The details of the curtailment programme will be developed to the satisfaction of the EPA prior to commissioning of the expansion.

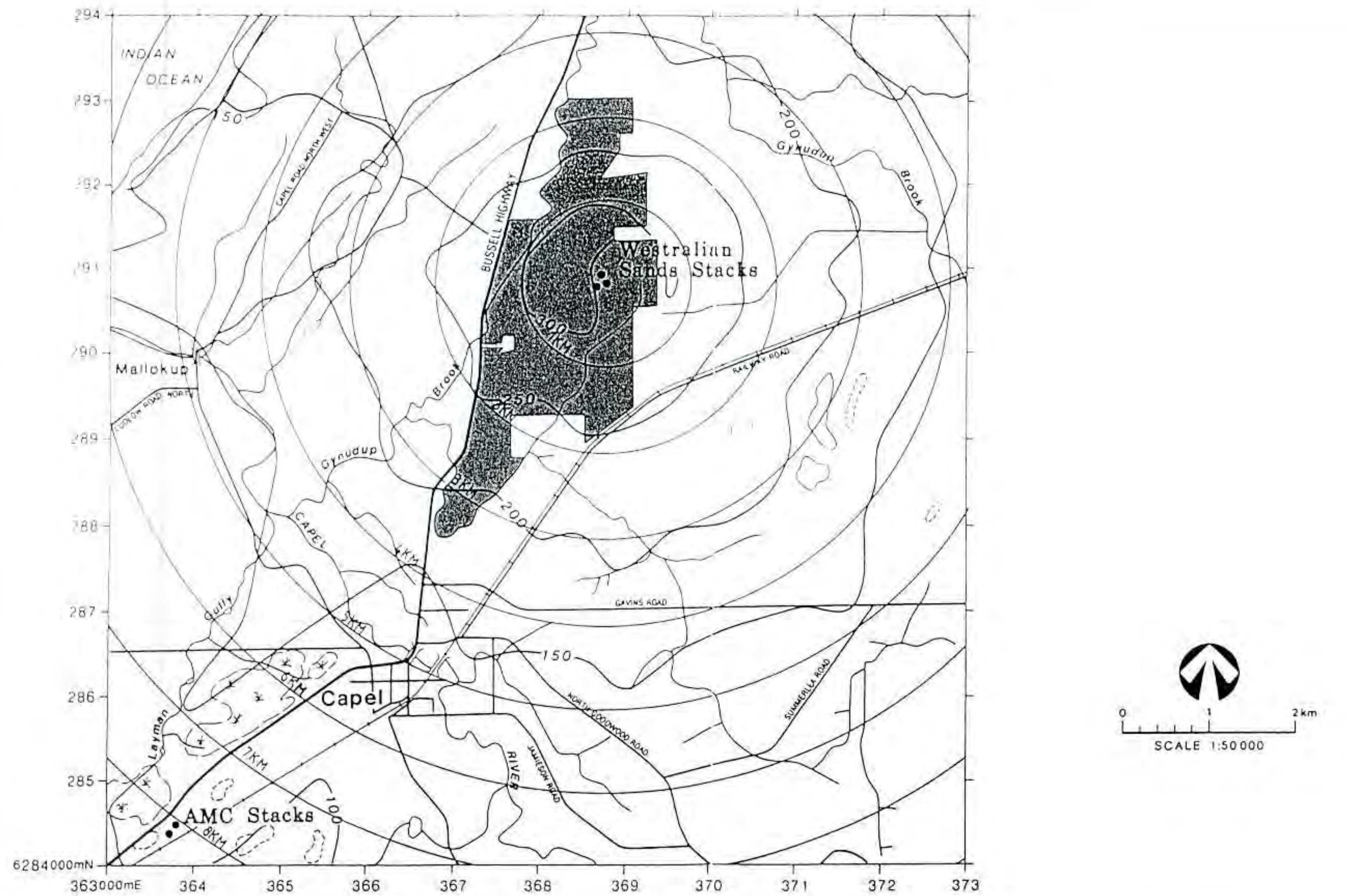

Figure 7.3: 9th Highest Hourly Ground Level SO_2 Concentration.

7.3.1.3 Monitoring Programme

A mobile SO_2 monitoring station is currently deployed by the company to assess the existing impact. This monitoring station will continue to be used to monitor the performance of the expanded plant. Weather data will also be collected at the site. The reliability of the models will be tested against real data to ensure ongoing community protection.

The company will review the data from monitoring with the EPA and will revise the level of stack emissions and the control strategy to ensure best plant practice and compliance with the environmental protection policy.

Commitments:

- ***The North Capel site will conform with the proposed EPA limits for SO_2 of 700 $\mu g/m^3$ never to be exceeded and the 350 $\mu g/m^3$ 99.9% compliance at the company boundaries.***

- ***The company will install instrumentation for continuous SO_2 monitoring on the main waste gas stack to the satisfaction of the EPA.***

- ***Ambient monitoring will be maintained but the sample monitoring site will be moved to a location approximately 1km from the stack and in the arc from west to southwest. (This location indicates the most likely impact during major inversions.)***

- ***The company will establish control procedures to ensure EPA licensed emission levels are not exceeded.***

- ***The company will prepare a management strategy, involving emission reduction during adverse meteorological conditions as predicted by the Bureau of Meteorology. This strategy will be prepared and agreed with the EPA prior to commissioning of the expansion. The strategy will be supported with data of stack emissions, ambient monitoring, meteorological data and model predictions for a period covering not less than one year's operation on the existing plant.***

7.3.2 Particulate and Dust Emissions

7.3.2.1 Controlled Emissions

Particulate or dust is entrained in the waste gases exiting the kiln. The waste gases will be passed through an electrostatic precipitator (ESP) to reduce the quantity of particulate which reach the discharge stack. An ESP has been chosen for dust removal because it is a dry scrubbing technique which consumes no water and because it is efficient at removing very fine (fume) particles which are not effectively collected by wet scrubbing. An ESP will consistently remove particulate to levels under 100 mg/m^3 and should regularly achieve levels of 50 mg/m^3.

Mechanical handling of dry materials (conveyors, screens etc) generate dust which will be controlled in the plant by containment and ventilation. The ventilated dust laden air will be passed through a bag filter to remove dust before discharge. A bag house will achieve similar effluent dust loadings to the ESP.

The levels of dust in stack emissions will be much less than the current plant licence limit.

Commitments:

- ***The company will treat kiln process gas and ventilation air streams to remove particulate to levels which ensure compliance with EPA licence conditions.***

- ***The company will monitor stacks to ensure compliance with EPA licence limit.***

- ***The company will maintain dust containment and dust removal systems in good working order to the satisfaction of the EPA.***

7.3.2.2 Fugitive Dust Emissions

Dust around the operations may be generated from stockpiles, transportation of raw materials and waste disposal. The expansion of the plant is not expected to increase the generation of dust on the site. Monitoring to date indicates that current management practices will ensure compliance with the environmental protection policy.

A number of procedures are routinely employed to control dust emissions.

Raw Materials

Coal, ilmenite and sulphur are all transported to the site by covered road truck. Lime consignments are delivered by tanker.

Roadways

Service roads around the plant and the North Capel pit are regularly watered to suppress dust generation by heavy vehicles. A sprinkler system is installed along the main access road to the North Capel pit.

Product Transport

Synthetic rutile is transported off site by road haulage. Trucks usually haul enclosed hoppers. Any open body trucks are covered by tarpaulins thus minimising dust generation.

Solid Waste Disposal

Dry char waste is deposited in the North Capel mine pit. Char dust is readily generated by wind action. To reduce dust emissions a layer of wet solid waste from the inert solids dam is placed over the char. Extensive sprinkler systems keep bare surfaces damp.

Road Sweeper

A commercial road sweeping contractor is regularly employed to clean the service roads within the plant area.

Wind Blown Dust

The most significant potential source of wind-blown dust is the North Capel mine pit where solid wastes are deposited.

Most of the solid wastes have a high moisture content when deposited and tend to dry with a firm surface which liberates little dust. While equipment movement compacts the damp material, it can also break the surface and generate fine dust if dry. Water tankers and sprinklers are used at the active dumping area.

Damp waste from the inert solids dam is used to cover deposited char and dry dust to suppress dust. A sprinkler system is also used when required.

Commitments:

- ***The company will ensure that all conveyors are covered and that all transfer points in the plant are enclosed and ventilated to prevent escape of generated dust.***

- ***The company will provide a large enclosed area for the storage of dry kiln product.***

- ***All trucks transporting dry material to, from and around the plant site will be required to cover potentially dusty loads to minimise wind disturbance of materials carried.***

- *Roads within the plant and disposal site will be swept and/or watered to minimise generation of airborne dust by vehicle movements.*

- *Stockpiles of materials will be located and managed to prevent fugitive emissions creating a nuisance outside the company's boundaries.*

- *The company will monitor plant and plant boundary dust loadings in air to maintain effectiveness of dust control measures.*

Odour Control

Control measures which are used successfully to minimise the impact of unpleasant odours will be maintained. Water will be treated to remove bacteria and algae, combustion systems burning coal will be maintained to ensure complete combustion and hydrogen sulphide will be collected and destroyed by combustion with air.

Commitments:

- *Extracted ground water will be treated to remove or kill bacteria and algae which may lead to the generation of mercaptan.*

- *All sources of hydrogen sulphide will be ventilated to the kiln afterburning chamber where the hydrogen sulphide will be destroyed by combustion with excess air.*

- *Coal combustion systems will be operated to maintain complete combustion.*

- *The company will investigate any odour which may originate from the plant and will take action to manage the making or release of odorous materials.*

7.4 IMPACT OF SOLID DISPOSAL

Solid wastes from the Synthetic Rutile Plant will be disposed of in the North Capel Mine Pit (Figure 7.2).

Potential environmental impacts of solid waste disposal are:-

- Leachate generation and contamination of ground water.
- Dust generation from wind erosion of uncovered wastes.
- Short and long term subsidence or ground instability.
- Unsightly appearance.

Management procedures to minimise the impact on ground water are described in Section 7.2.4.

Dust emissions can occur during the dry summer months. Dust suppression procedures include:-

. Placing source materials of dust deep in the pit.
. Laying heavier damp materials over lighter, dust-prone materials.
. Regular watering of roadways and solids disposal area.
. Prompt profiling and rehabilitation of filled sections.

Subsidence has been monitored for current activities. The materials appear to compact readily and support a stable surface. Regular monitoring by survey will be continued.

A programme to contour filled areas, cover with clean sand and rehabilitate with grasses and trees will be undertaken to minimise the amount of exposed fill.

Commitments:

- ***The company will develop detailed procedures for controlling solid waste disposal in the North Capel pit:***
  - ***All waste material will be placed at least 1 metre above the winter water table.***
  - ***Material will be compacted to minimise leachate generation.***
  - ***The pit profile will be maintained to maximise rain water run-off.***
  - ***Solid wastes will be covered by a minimum of 1 metre of clean sand prior to rehabilitation.***

- ***Dust generation in the active solids disposal area will be minimised by sprinkler systems and water trucks to dampen the surface and prevent nuisance outside the company's boundary.***

- ***Records of disposed materials will be maintained and will be available to future land users on purchasing.***

- ***Surface surveys will be annually carried out to determine stability of the ground.***

- ***Trials will be undertaken to determine the best species for rehabilitation and to determine beneficial short and medium term land use.***

7.5 IMPACT OF PLANT NOISE

Noise control provisions have been incorporated into the proposal in the selection of the basic processes and equipment and by detailed design to minimise predicted sound levels.

Equipment suppliers will be expected to meet the engineering noise specifications as defined in the Noise Abatement Regulations of 1983.

Engineering modifications to the existing plant will continue in order to meet environmental noise requirements. The programme of monitoring and modifying plant will continue through commissioning of the expansion. Money will be budgeted for retrofitting noise suppression equipment in the expanded plant so that monitored values indicate a satisfactory environment.

Attenuation methods may include:-

. Further lagging of pipes, barriers and enclosure for aeration tank drives.

Predicted noise emissions as shown in Appendix 5 (adverse conditions) will need to be improved to reduce nuisance to neighbours. Methods of successful noise reduction employed in the existing plant will be applied in the extension. The predictions from modelling have been based on a similar operating plant. It is the company's intention to improve on this situation once the final plant flow sheet has been decided and equipment selection is undertaken. Ultimately the success of the programme will be determined by monitoring once the plant is commissioned. The company will undertake to provide a satisfactory level of noise at start up or within two years of start up of the expansion.

Commitments:

- ***Noise emissions will be regularly monitored to ensure compliance with EPA standards.***

- ***Engineering modifications to the existing plant will be undertaken in order to reduce impact in the worst case scenario.***

- ***A budget allocation will be committed for noise suppression work on the expanded plant after start up. Monitoring will determine if work is required or not. The company will undertake to progress modifications with priorities as agreed with the EPA.***

7.6 SOCIO-ECONOMIC IMPACT

Demographic and Employment

The proposed expansion will result in the recruitment of 50 new employees. The positions will involve skilled, semi-skilled and unskilled tasks. The local employment policy will mean most of these positions will be filled from the local workpool.

The level of local employment opportunities generated during the construction phase will depend on the hiring policy of the contractors undertaking the construction and the availability of the required skills in the local labour pool.

The employment opportunities within the local region will provide significant benefits to local communities and businesses presently suffering from the rural economic recession.

Housing and Accommodation

Most of the 50 new employees will be recruited locally. Additional demand for accommodation will be minimal. Any new residents could easily be accommodated in the Bunbury, Capel area which has a ready supply of residential land and houses for purchase. Rental accommodation is also available.

Temporary accommodation for the construction workforce would primarily consist of available rental accommodation, including short term caravan, cabin and hotel/motel accommodation. Bunbury and Capel have an ample supply of short term accommodation (See Section 4.11). The final arrangements for housing the construction workforce will be determined through discussions with the contracting company, the relevant shires and the proponent. A management plan will be drawn up to the satisfaction of the Shire of Capel and the EPA.

Community Facilities and Services

Given the growth experienced in the Greater Bunbury Area in recent years, planning measures undertaken by the local government authorities should adequately cater for any increase in the population as a result of the project.

Most new employees will be local residents, therefore the existing supply of community facilities and services are not expected to be placed under excessive demands.

Economics

Substantial economic benefits are expected to flow from the proposed project.

Wages associated with construction and operation of the project will add to the economic well–being of the Shire and region. Direct wage payments during the construction phase are expected to peak at $0.5M per month. The wage bill annually during the operational phase is expected to be an extra $2.2M ($1992). Significant flow–on income effects are expected to result from this injection into the local economy.

Maintenance costs are estimated to value $3M per annum of which the majority will be directed to South–West contractors.

The purchase of raw materials predominantly from within Western Australia is expected to be valued at between $6 – $8M annually.

The proposed project's operations will make a positive contribution to the country's export income to the extent of an average $60M ($1992) per year.

Commitments:

- ***The company will maintain a local priority policy in terms of employment and supply of goods and services.***

- ***Should a construction camp be decided upon, a management plan will be drawn up in consultation with the Shire of Capel and to the satisfaction of the EPA.***

Transport

Traffic

During the construction phase, the workforce will travel mainly from Bunbury or Capel.

The existing synthetic rutile plant is annually shut down for maintenance. During this time up to 200 extra people are employed on the site. Car pooling is popular and some contractors transport their workers in small buses. No traffic problems have been experienced and it is anticipated that the construction phase of the plant expansion will result in a comparable situation.

The operational workforce will probably follow the existing distribution with respect to location of residence:

46% Bunbury
17% Busselton
27% Capel/Boyanup
10% Other.

This will result in an extra 25 people from Bunbury, half of whom will be shift workers and half day workers. The Capel–Bunbury road will be dual carriageway by the time the plant is commissioned. The impact of extra traffic on roads in the area will be negligible.

Approximately 8 extra workers from Busselton, 14 from Capel/Boyanup and 3 from other areas are not expected to have a significant impact on the existing conditions of the local roads.

The number of truck movements around the synthetic rutile plant would increase during the construction phase. Road changes around the plant will be implemented before the expansion commences to maintain safety conditions: Yeardy Road will be closed and Cable Mine Road opened up to through traffic as an alternative route. (See Figure 7.4). Negotiations are well progressed with the Shire to effect these changes at the time of writing.

Product and Raw Material Transport

All raw materials and product will be transported by road. Most material movements are over short distances: Capel to North Capel (ilmenite) and North Capel to Bunbury (synthetic rutile). Coal comes from Collie and small quantities of other raw materials come from Perth.

Some ilmenite from north of Perth is railed to Bunbury and off–loaded to be transported by truck to the North Capel site.

The expansion will result in a doubling of raw materials and product transport to the site.

Ilmenite and synthetic rutile constitute the major material movements. The impact on major roads will be minimal. The expansion will not require a corresponding increase of ilmenite production; ilmenite which would otherwise be exported will be upgraded to synthetic rutile. Combined ilmenite and synthetic rutile truck movements on the Bussell Highway will be very similar to the existing numbers.

Coal from Collie will double from ten loads per day to 21 loads per day – 42 truck movements. Coal is transported five days per week between the hours of 7am and 10pm. Trucks use the Collie Highway, Bunbury Bypass and Bussell Highway.

Coal transport will be managed to minimise the impacts on residences along the route. Contractors will be required to submit proposals for fleet design with the aim of minimising noise, dust generation and material spillage. The Collie Shire Council will be

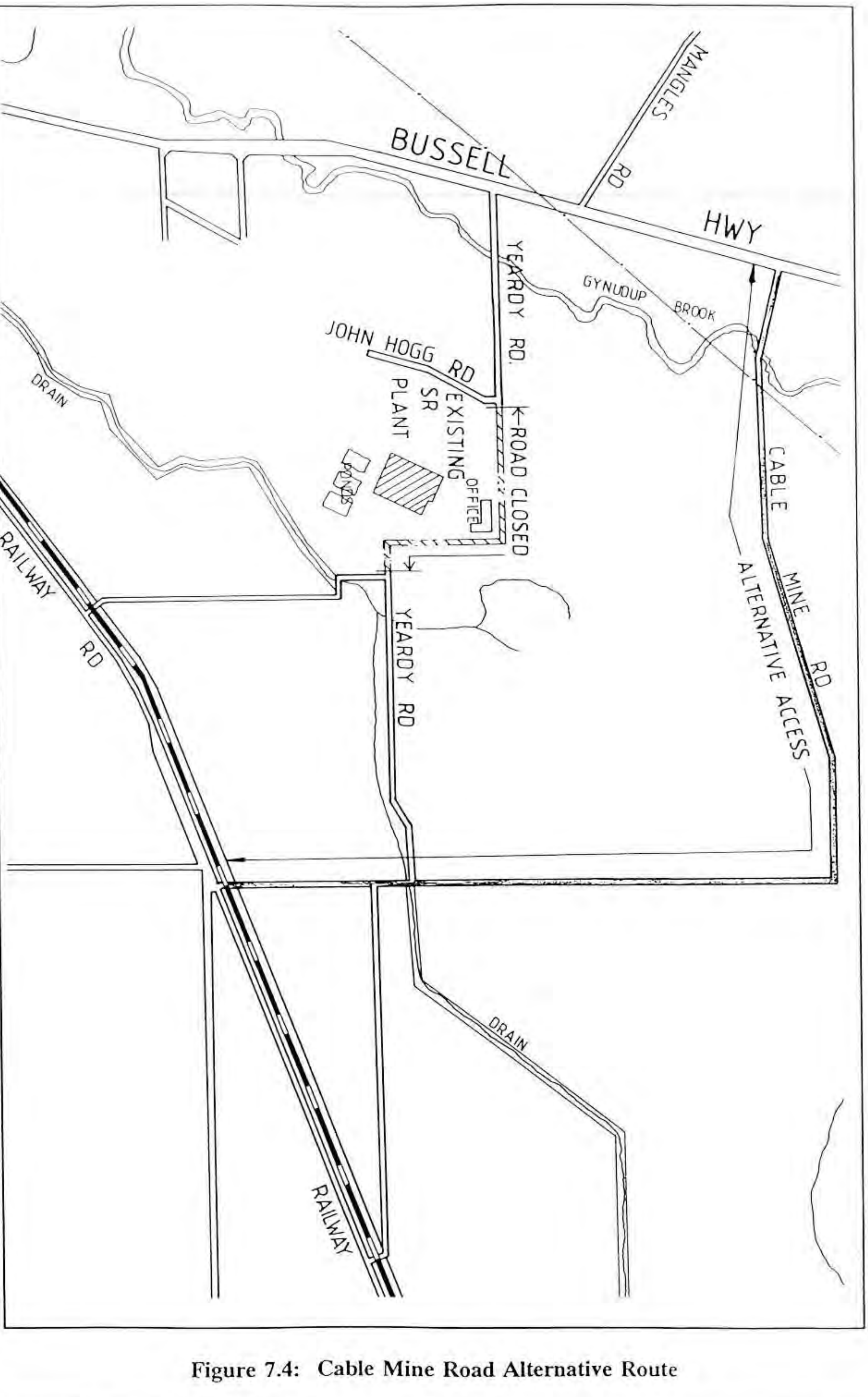

Figure 7.4: Cable Mine Road Alternative Route

consulted on the evaluation and decision with respect to design. It will be a requirement that systems installed on the fleet to minimise social and environmental impacts are maintained and used appropriately.

Provision has been made in the expansion to accommodate the introduction of rail facilities at a later date. Rail transport of one material only is uneconomic. As local mines are exhausted and more distant mines opened, rail may become more viable, practically and economically. Discussions with Westrail will continue.

Commitment:

- ***The company will require road transport contractor to supply and maintain the appropriate fleet to minimise spillage, noise and dust on the roads.***

7.7 EMERGENCY PLANS

The bulk handling of some raw materials requires special procedures to be developed that will automatically come into place should an incident occur that results in a spillage of material.

The materials of concern that are handled at the synthetic rutile plant are:-

- Sulphuric acid.
- Quicklime.

These materials, due to their reactive nature, are contained in specialist containers within the plant and delivered in designated transport. The operating plant personnel will have been trained in specific designed procedures to handle any incident on site. This training will be conducted by specialists from the supplier companies.

Any large processing plant, of which this proposal is typical, is exposed to the potential of an emergency occurrence of the following type:-

Fire

Injury

The incidence of fire will be controlled by automatic detectors in buildings and substations and controlled by the use of fire extinguishers or the reticulated water system that will be installed. All personnel on shift have been, and continue to be, trained in the use of fire fighting equipment.

Procedures to deal with injury are already established at the site. The company encourages and supports all employees to develop first aid skill levels to that of occupational first aider. Emergency centres have been established at the site and specific drills of a rescue nature practised.

Pre-specified pick-up points for ambulance, should the need arise, have been in place for a number of years.

Commitment:

- *The company will have in place drills designed to handle the following emergency situations:*
  Spillage of sulphuric acid.
  Spillage of quicklime.
  Fire.
  Injury.

  These drills will be set up as part of the employees' regular training and updated as and when required.

7.8 RISK ANALYSIS

The Becher process utilises well known and mature technology, conventional materials of construction and equipment. The process has been demonstrated to contain no features that need to be considered of 'high' risk to personnel within the production facility or external to the plant boundaries.

The alternative technology under consideration by virtue of its operation at elevated pressure, contained oxygen and possibility to generate hydrogen gas has a raised risk potential. Following development of detailed flow sheet, equipment selection and process control principles, a full risk analysis of the alternative technology will be undertaken to ensure correct controls and equipment are put into place prior to commissioning.

Commitment:

- *Should the company select the alternative technology for inclusion into the proposed plant expansion, then that portion of the plant and process not associated with the traditional Becher process will be subjected to a full risk analysis.*

7.9 WASTE MANAGEMENT STRATEGY

Westralian Sands will manage the synthetic rutile capacity expansion according to the licences set by the EPA and WAWA. Operations will also be in accordance with the company's environmental policy (Appendix 7).

Waste management strategies of 'Reduce, Reuse, Recycle' have been employed in the design of this expansion.

Reduce

Water consumption has been reduced through employment of dry scrubbing techniques for kiln waste gas and plant ventilation scrubbing.

Energy consumption will be reduced by recovering some of the heat from the kiln waste gas. Several options are still under review – the most likely option would be to provide hot air for product drying saving the combustion of 6,000 tonnes of coal annually.

Material usage efficiencies are constantly under review to reduce material unit consumption. All major commodities are used more efficiently than design in the existing plant. Techniques developed in the existing plant will be fully implemented in the expansion.

Reuse

Water used for cooling kiln product will report to a cooling tower and will be reused. It will also be used to preheat liquor used later in the process.

Coal is charred in the kiln, separated from the intermediate product 'reduced ilmenite' and reused in the kiln.

Spent acid leach liquor is reused to extract acid more effectively and reduce fresh acid consumption.

Ammonium chloride liquor is reused.

Recycle

Coal char cannot be used indefinitely in the kiln as the ash level builds up as the fuel is extracted. Used char is recycled for use in brickworks and foundries.

Iron oxide waste may be recycled as a soil conditioner according to research currently being carried out by UWA. Small quantities are recycled for use in a number of specialty areas. Other uses are being reviewed.

Neutralised effluent also shows high potential as a soil additive containing complex oxy hydroxides of iron which bind nutrients into conditioned soils. The solids also contain gypsum which is itself a useful soil conditioner.

Treated discharge water may be recycled and used in locations such as dampening of dry scrubbed dust for handling and disposal.

Used kiln grease which was previously dumped as a waste is now recycled to the kiln as a minor fuel.

8. MANAGEMENT AND MONITORING

8.1 MANAGEMENT AND ADMINISTRATION

The maintenance of an environmental programme requires that internal responsibilities and accountabilities are clearly defined. This CER identifies commitments by the company to implement controls on the proposed expanded plant.

Production Monitoring

It is the responsibility of the Production Manager – Synthetic Rutile to ensure that operating practices and equipment utility are maintained to the standards required by the commitments and licences. Continuous plant monitoring equipment will be maintained by specialist contractors or internal engineering staff at the request of the Production Manager.

Environmental Monitoring

The routine monitoring programme will be directed by the Senior Environmental Officer who will ensure equipment, staff and specialist contractors are obtained to meet the requirements of the programme in Section 8.2. The Senior Environmental Officer will review and report on the monitored data to senior management and licensing authorities. Items of non compliance or potential non compliance will be highlighted to the responsible manager, senior management and the Environmental Review Committee. Special reports on non compliance to government authorities will be collated and submitted by the Senior Environmental Officer.

Community Consultation

Public interest in the CER and the ongoing operations of the process may be raised directly or through the EPA. The Community Liaison Officer will be responsible for receiving comments, queries or complaints. The Officer will record the communication and respond appropriately. The Community Liaison Officer will be particularly involved in items of social impact and will attend meetings of local government and community bodies. The Community Liaison Officer will be responsible for presenting views on public perception or changing expectations to management and the Environmental Review Committee.

Workforce Awareness

The operation of the plant is delegated to supervisors and operators who are present 24 hours a day all year. It is important that these people have clear operating procedures and practices and are sufficiently knowledgeable about the potential impacts under their control so that they may take prompt and appropriate action to prevent or reduce an undesirable impact.

Auditing

A monitoring and control programme needs to be reviewed from time to time to ensure its effectiveness. This is best done by an auditing process. Auditing may be performed by qualified persons internal or external to the company. It will be the responsibility of the Technical Services Superintendent to arrange for an audit of the area and to present the findings and recommendations of the audit to senior management and the company's Environmental Review Committee.

Commitments:

- ***The company will produce an Area Management Plan which clearly defines short, medium and long term objectives, management and monitoring procedures. It will incorporate commitments, communication and licensing conditions and will identify responsibilities and accountabilities.***

- ***The company will include environmental responsibilities in the job descriptions of all employees.***

- ***The company will ensure that all employees receive sufficient training in environmental management procedures and practices to carry out their duties.***

- ***The company will maintain a reporting procedure to promptly identify non compliance or potential non compliance to senior management and government authorities.***

- ***The company will conduct audits on environmental performance and practices at intervals not exceeding two years.***

8.2 MONITORING PROGRAMME

Details of the monitoring programme to support commitments are set out in Table 8.1. Measurement methods will be subject to review but will be selected on the basis of availability, applicability to the sensitivity required and latest technological developments. Where visual inspections are required, a note will be included on a log sheet for record purposes.

TABLE 8.1

		MONITORING		PERSONNEL RESPONSIBLE	
	LOCATION	INVESTIGATED ITEMS	REPEAT FREQUENCY	MANAGEMENT CONTROL	CONDUCT THE TASK
AIR QUALITY:	Within WSL's plant boundary	Dust, radioactivity	3 months	Senior Environmental Officer	Occupational Health Officer
	Kiln stack	Temperature, moisture, flow rate, particulates, H_2O	12 months	Senior Environmental Officer	Consultant
	Hygiene stack	Temperature, moisture, flow rate, particulates	12 months	Senior Environmental Officer	Consultant
	External to WSL plant boundaries	SO_2	Continuous	Senior Environmental Officer	Occupational Health Officer
	Kiln stack	SO_2, opacity	Continuous	SR Plant Production Manager	Instrumented
	Plant, stockpiles, disposal site	Fugitive dust, visual impact	Daily	SR Plant Production Manager	Foreman, Operator
	Hygiene stack/Bag house	Escaping dust, visual impact	Daily	SR Plant Production Manager	Foreman, Operator
WASTE WATER QUALITY:	SR discharge to Elgin Drain	Flow rate, pH, conductivity, temperature	Continuous	SR Plant Production Manager	Instrumented
		Fe, Mn, Zn, SO_4 PO_4, NO_2, NO_3, Cl, Cu, Cr, Ni, Pb, NH_3-free, NH_3-total, suspended solids, discolouration, odour, floating matter.	Weekly	Senior Environmental Officer	Technical Assistant
		Ca, Mg, Na, K	Monthly	Senior Environmental Officer	Technical Assistant

WASTE WATER QUALITY (Cont):

LOCATION	MONITORING		PERSONNEL RESPONSIBLE	
	INVESTIGATED ITEMS	REPEAT FREQUENCY	MANAGEMENT CONTROL	CONDUCT THE TASK
Extended artificial wetland discharge	Temperature, pH, conductivity, Fe, Mn, Zn, Cl, SO_4, NO_2, NO_3, PO_4	Weekly	Senior Environmental Officer	Technical Assistant
	Ca, Pb, NH_3-free, NH_3-total	Monthly	Senior Environmental Officer	Technical Assistant
Storage dam discharge	pH	Continuous	Senior Environmental Officer	Instrument
	Fe, Mn, Zn; Cl, SO_4, NO_2. NO_3, PO_4	Weekly	Senior Environmental Officer	Technical Assistant
	Ca, Pb, NH_3-free, NH_3-total	Monthly	Senior Environmental Officer	Technical Assistant
Neutralised effluent overflow	Temperature, pH, conductivity	Continuous	Senior Environmental Officer	Instrument
	Cl, SO_4, Fe, Mn, Zn, NO_2, NO_3, PO_4	Weekly	Senior Environmental Officer	Technical Assistant
	Ca, Pb, NH_3-free, NH_3-total	Monthly	Senior Environmental Officer	Technical Assistant
Minor artificial wetland discharge	Temperature, pH, conductivity, Cl, Fe, Mn, Zn, NO_2, NO_3, PO_4	Weekly	Senior Environmental Officer	Technical Assistant
	Ca, pH, NH_3-free, NH_3-total	Monthly	Senior Environmental Officer	Technical Assistant
Western storm water drain	pH, conductivity, Fe, Mn, Zn, Cl, SO_4, NO_2, NO_3, PO_4	Weekly	Senior Environmental Officer	Technical Assistant
	NH_3-free, NH_3-total	Monthly	Senior Environmental Officer	Technical Assistant

	LOCATION	MONITORING: INVESTIGATED ITEMS	MONITORING: REPEAT FREQUENCY	PERSONNEL RESPONSIBLE: MANAGEMENT CONTROL	PERSONNEL RESPONSIBLE: CONDUCT THE TASK
GROUND WATER QUALITY:	SR plant equipment boundary and North Capel pit (monitoring bores)	Water depth, pH, conductivity	3 months	Senior Environmental Officer	Technical Assistant
		Cl, NO_3, SO_4, Fe, Mn,	6 months	Senior Environmental Officer	Technical Assistant
		Zn, NH_3-free, NH_3-total	12 months	Senior Environmental Officer	Technical Assistant
		Cu, Cr, Ni, Pb	Occasionally	Senior Environmental Officer	Technical Assistant
	Pipelines	Leaks	Daily	SR Plant Production Manager	Foreman, Operator
	Liquor containment	Leaks, spills, overflows	Every shift	SR Plant Production Manager	Operator
GROUND WATER USAGE:	Production bores	Water consumption, level	Monthly	Senior Environmental Officer	Technical Assistant
	Aquifer in SR plant area	Performance	12 months	Senior Environmental Officer	Consultant
MINOR ELEMENT AUDIT:	Plant input and output stream	Pb, Zn, Cu, Cd, Cr, Sn, Ni, As, Hg, U, Th	24 months	SR Plant Production Manager	Consultant or Metallurgist
GROUND STABILITY:	North Capel pit	Ground level	12 months	SR Plant Production Manager	Surveyor
NOISE:	External to WSL plant boundaries	Noise intensity	12 months	Senior Environmental Officer	Occupational Health Officer

		MONITORING		PERSONNEL RESPONSIBLE	
	LOCATION	INVESTIGATED ITEMS	REPEAT FREQUENCY	MANAGEMENT CONTROL	CONDUCT THE TASK
SOCIAL ISSUES:	Capel	Shire Communities Association	6 months	Community Liaison Officer	Community Liaison Officer
		Industry Liaison Committee	3 months	Community Liaison Officer	Community Liaison Officer

The monitoring programme will be reviewed periodically. Frequency of monitoring may be varied at the time of review and monitoring scope may also be changed. Variation of the programme will be based on security required to ensure that impacts are detected and rectified. The review will consider past monitoring performance and the comfort level compared to compliance. Frequencies may be increased or decreased, items included or removed or a method or type of monitoring changed. Where monitoring is covered by a specific commitment or licence, no change will be made without consultation with the responsible authority.

Commitments:

- *The company will maintain a programme of monitoring to support the management of environmental impacts.*

- *The company will review the monitoring programme to ensure that it is appropriate to the needs of good environmental management.*

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REFERENCES

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LIST OF COMMITMENTS

LIST OF COMMITMENTS

No.	COMMITMENT
	IMPACT DURING CONSTRUCTION
1.	The generation of dust as a result of construction activities will be managed by: • ensuring areas disturbed and left bare are kept to a minimum. • keeping unsurfaced roads dampened.
	IMPACT ON WATER RESOURCES **Ground Water Consumption**
2.	After consultation with EPA and WAWA, the existing monitoring programmes will be expanded to collect data for a regular review of aquifer performance.
3.	The company will maintain ongoing liaison and consultation with the EPA and Water Authority of WA with respect to aquifer performance.
4.	Water consumption will be minimised through recycling, dry scrubbing of gases and re–using saline water at appropriate locations.
5.	Should other demands on the aquifer compound to have a detrimental impact, the company will review with WAWA ways to reduce its impact on ground water supply.
	Surface Water Discharge
6.	A controlled monitoring point consistent with WAWA standards will be established prior to discharge into the Elgin Drain.
7.	The surface water discharge will be maintained at the licensed quality and quantity specified by the WAWA.
8.	Monitoring will be conducted as in Table 8.1. Results will be collated and submitted to the WAWA on a regular basis as requested.
9.	The company will ensure that ongoing discussions are maintained with WAWA to develop improvements in the surface water discharge.
10.	Should monitoring detect breaches of the discharge criteria set by WAWA then the source of the deviation will be identified and corrective action promptly taken. If this requires operations to be shut down, then that action will be taken.
	Site Run–off
11.	To avoid contamination of surface run–off, the company will: • maintain the physical integrity of all bunded and contained areas • regularly clean all roadways and open plant areas; and, • regularly clean plant drainage ways.

No.	COMMITMENT
	IMPACT ON WATER RESOURCES (Cont.) **Ground Water Quality** *Dam Leakage*
12.	The company will construct double membrane containment dams to contain acidic and ammonium chloride liquors. The secondary membrane will have the facility to direct leaked material to detection and collection systems.
13.	The company will maintain strict procedures to check the integrity of primary membranes in dams before being placed in use or returned to use.
	Process Liquor Transport
14.	Overland pipelines of saline or acidic liquor will be run in lined troughs draining to instrumented recovery sumps.
15.	Where pipelines cannot be treated to secondary containment the pipe will be continuous and will be of a high integrity material.
16.	Prompt action will be taken to prevent leaks or spills reporting to ground water. Action will include plant shutdown if necessary.
	Solid Waste Disposal Pit
17.	Ground water monitoring as agreed with WAWA around the North Capel disposal pit will continue. Action will be taken to identify the source of any quality deterioration. Ground water recovery and clay capping are alternatives which may be employed if required.
	Material Spillage and Storage
18.	All materials spilled during transport or transfer will be promptly disposed of in a manner acceptable to the EPA.
19.	Sulphuric acid will be transported in steel road tankers and transferred to a steel storage vessel in a secondary containment bunded enclosure. The transfer point will be designed to contain spillage during transfer.
20.	Sulphur and ammonium chloride will be transported in conventional road transport and will be stored under cover on concrete flooring.
21.	Lime will be transported in a steel road tanker and transferred to a steel storage silo. The transfer point will drain to local effluent pondage.
	Equipment Failure
22.	Processing equipment and plant pipe runs handling liquids, other than water, will be bunded and serviced by automatically activated recovery sumps.
23.	In the event of a spill escaping the bunding, soil and ground water will be tested and recovery initiated if required.

No.	COMMITMENT
	IMPACT ON WATER RESOURCES **Ground Water Quality (Cont.)** ***Monitoring and Recovery***
24.	The company will revise its ground water monitoring programme in consultation with WAWA to service the expanded operating site.
25.	Water quality will be reviewed with WAWA on a regular basis. Water that is adversely affected will be recovered and treated in a manner acceptable to WAWA.
	IMPACT ON AIR QUALITY **Sulphur Dioxide**
26.	The North Capel site will conform with the proposed EPA limits for SO_2 of 700 $\mu g/m^3$ never to be exceeded and the 350 $\mu g/m^3$ 99.9% compliance at the site boundaries.
27.	The company will install instrumentation for continuous SO_2 monitoring on the main waste gas stack to the satisfaction of the EPA.
28.	Ambient monitoring will be maintained but the sample monitoring site will be moved to a location approximately 1km from the stack and in the arc from west to southwest. (This location indicates the most likely impact during major inversions.)
29.	The company will establish control procedures to ensure EPA licensed emission levels are not exceeded.
30.	The company will prepare a management strategy, involving emission reduction during adverse meteorological conditions as predicted by the Bureau of Meteorology. This strategy will be prepared and agreed with the EPA prior to commissioning of the expansion. The strategy will be supported with data of stack emissions, ambient monitoring, meteorological data and model predictions for a period covering not less than one year's operation on the existing plant.
	Particulate and Dust Emissions ***Controlled Emissions***
31.	The company will treat kiln process gas and ventilation air streams to remove particulate to levels which ensure compliance with EPA licence conditions.
32.	The company will monitor stacks to ensure compliance with EPA licence limit.
33.	The company will maintain dust containment and dust removal systems in good working order to the satisfaction of the EPA.

No.	COMMITMENT
	IMPACT ON AIR QUALITY **Particulate and Dust Emissions (Cont.)** ***Fugitive Dust Emissions***
34.	The company will ensure that all conveyors are covered and that all transfer points in the plant are enclosed and ventilated to prevent escape of generated dust.
35.	The company will provide a large enclosed area for the storage of dry kiln product.
36.	All trucks transporting dry material to, from and around the plant site will be required to cover potentially dusty loads to minimise wind disturbance of materials carried.
37.	Roads within the plant and disposal site will be swept and/or watered to minimise generation of airborne dust by vehicle movements.
38.	Stockpiles of materials will be located and managed to prevent fugitive emissions creating a nuisance outside the company's boundaries.
39.	The company will monitor plant and plant boundary dust loadings in air to maintain effectiveness of dust control measures.
	Odour Control
40.	Extracted ground water will be treated to remove or kill bacteria and algae which may lead to the generation of mercaptan.
41.	All sources of hydrogen sulphide will be ventilated to the kiln afterburning chamber where the hydrogen sulphide will be destroyed by combustion with excess air.
42.	Coal combustion systems will be operated to maintain complete combustion.
43.	The company will investigate any odour which may originate from the plant and will take action to manage the making or release of odorous materials.
	IMPACT OF SOLID DISPOSAL
44.	The company will develop detailed procedures for controlling solid waste disposal in the North Capel pit: – All waste material will be placed at least 1 metre above the winter water table. – Material will be compacted to minimise leachate generation. – The pit profile will be maintained to maximise rain water run–off. – Solid wastes will be covered by a minimum of 1 metre of clean sand prior to rehabilitation.

No.	COMMITMENT
	IMPACT OF SOLID DISPOSAL (Cont.)
45.	Dust generation in the active solids disposal area will be minimised by sprinkler systems and water trucks to dampen the surface and prevent nuisance outside the company's boundary.
46.	Records of disposed materials will be maintained and will be available to future land users on purchasing.
47.	Surface surveys will be annually carried out to determine stability of the ground.
48.	Trials will be undertaken to determine the best species for rehabilitation and to determine beneficial short and medium term land use.
	IMPACT OF PLANT NOISE
49.	Noise emissions will be regularly monitored to ensure compliance with EPA standards.
50.	Engineering modifications to the existing plant will be undertaken in order to reduce impact in the worst case scenario.
51.	A budget allocation will be committed for noise suppression work on the expanded plant after start up. Monitoring will determine if work is required or not. The company will undertake to progress modifications with priorities as agreed with the EPA.
	SOCIO-ECONOMIC IMPACT
52.	The company will maintain a local priority policy in terms of employment and supply of goods and services.
53.	Should a construction camp be decided upon, a management plan will be drawn up in consultation with the Shire of Capel and to the satisfaction of the EPA.
	Transport
54.	The company will require road transport contractor to supply and maintain the appropriate fleet to minimise spillage, noise and dust on the roads.

No.	COMMITMENT
55.	**EMERGENCY PLANS** The company will have in place drills designed to handle the following emergency situations: Spillage of sulphuric acid. Spillage of quicklime. Fire. Injury. These drills will be set up as part of the employees' regular training and updated as and when required.
56.	**RISK ANALYSIS** Should the company select the alternative technology for inclusion into the proposed plant expansion, then that portion of the plant and process not associated with the traditional Becher process will be subjected to a full risk analysis.
57.	**MANAGEMENT AND ADMINISTRATION** The company will produce an Area Management Plan which clearly defines short, medium and long term objectives, management and monitoring procedures. It will incorporate commitments, communication and licensing conditions and will identify responsibilities and accountabilities.
58.	The company will include environmental responsibilities in the job descriptions of all employees.
59.	The company will ensure that all employees receive sufficient training in environmental management procedures and practices to carry out their duties.
60.	The company will maintain a reporting procedure to promptly identify non compliance or potential non compliance to senior management and government authorities.
61.	The company will conduct audits on environmental performance and practices at intervals not exceeding two years.
62.	**MONITORING PROGRAMME** The company will maintain a programme of monitoring to support the management of environmental impacts.
63.	The company will review the monitoring programme to ensure that it is appropriate to the needs of good environmental management.

GLOSSARY

GLOSSARY

After-burning	High temperature combustion of volatile kiln gases to produce carbon dioxide and sulphur dioxide.
Aquaclude	An impervious layer of rock or sediment.
Aquifer	A layer of rock which holds water and allows water to pass through.
Char	Partially burnt coal.
Dedusting	Process by which dust is removed from waste gas stream.
Fly-ash	Fine ash from fully combusted coal.
Leachate	A solution generated by rain water percolating through solid materials.
Liquor	Water based solution containing process chemicals.
Mercaptan	Naturally occurring substances containing sulphur.
Synthetic Rutile	Man-made (material) - mineral containing 91-44% titanium dioxide.
Titanium Slag	Mineral containing 80-85% titanium dioxide.

ABBREVIATIONS

LIST OF ABBREVIATIONS

%	Percentage
μg	Micrograms
a	Annum
Al_2O_3	Alumina
As	Arsenic
bar	Unit of pressure
Ca	Calcium
CaO	Calcium oxide
Cd	Cadmium
CER	Consultative environmental review
Cl	Chlorine
CO	Carbon monoxide
CO_2	Carbon dioxide
Cr	Chromium
Cr_2O_3	Chromic oxide
CSIRO	Commonwealth Scientific Industrial Research Organisation
Cu	Copper
dBA	Decibels on A scale
DSD	Department of State Development
EPA	Western Australian Environmental Protection Authority
ERMP	Environmental review and management programme
Fe	Iron
g	Grams
H_2	Hydrogen
H_2O	Water
H_2S	Hydrogen sulphide
Hg	Mercury
K	Potassium
kl	Kilolitres
km	Kilometres
kV	Kilovolts
kW	Kilowatts
l	Litre
m	Metres
m^3	Cubic metres
mg	Milligrams

Mg	Magnesium
MgO	Magnesium oxide
mm	Millimetres
Mn	Manganese
MnO	Manganese oxide
N	Normal
N_2	Nitrogen gas
Na	Sodium
NH_3	Ammonia
Ni	Nickel
NNE	North north east
NO_2	Nitrate
NO_3	Nitrate
O_2	Oxygen
Pb	Lead
PER	Public environmental review
pH	Measure of acidity
PO_4	Phosphate
ppm	Parts per million
PSA	Pressure swing absorption
s	Seconds
SECWA	State Electricity Commission of Western Australia
SiO_2	Silica
Sn	Tin
SO_2	Sulphur dioxide
SO_4	Sulphate
Sr	Strontium
SR	Synthetic rutile
SSE	South south east
t/a	Tonnes per annum
t	Tonnes
TDS	Total dissolved salts
Th	Thorium
ThO_2	Thorium oxide
TiO_2	Titanium dioxide
U	Uranium

U_3O_8	Uranium oxide
USA	United States of America
V_2O_5	Vanadium pentoxide
Vol	Volume
WA	Western Australia
WAWA	Water Authority of Western Australia
Zn	Zinc
ZrO_2	Zirconium oxide
°C	Degrees centigrade

APPENDIX 1

GUIDELINES FOR CONSULTATIVE ENVIRONMENTAL REVIEW

THE DUPLICATION OF SYNTHETIC RUTILE CAPACITY.

WESTRALIAN SANDS LIMITED, CAPEL

Overview

In Western Australia all environmental reviews are conducted in order to protect the environment. The fundamental requirement is for the proponent to describe what they propose to do, to identify and discuss the potential environmental impacts of the proposal, and then to discribe how those potential environmental impacts will be managed so that the environment is protected.

If the proponent can demonstrate that the environment will be protected then the proposal will be found environmentally acceptable. If the proponent cannot show that the environment would be protected, or cannot demonstrate that proposed environmental management strategies would be effective, the Environmental Protection Authority (EPA) will recommend against the proposal.

Throughout the process it is the aim of the EPA to advise and assist the proponent to improve or modify the proposal in such a way that the environment is protected or benefited. However, the Western Australian environmental review process is proponent driven, and it is up to the proponent to identify potential environmental impacts, and to design and implement proposals which protect the environment.

For this proposal, protecting the environment means that the duplication of Synthetic Rutile capacity of Westralian Sands Capel is to be managed in such a way that aims to improve or maintain the natural and social environment of that area. Where this objective can not be readily achieved, strategies to mitigate any potential impacts will be required.

These guidelines identify issues that should be addressed within the Consultative Environmental Review (CER). The guidelines are not intended to be exhaustive and the proponent may consider that other issues should also be addressed in the document. The format of the CER is the proponent's responsibility but care should be taken to ensure that topics such as the existing environment and project description are adequately addressed.

The CER is intended to be a public document and should be easily read by the general public. Its purpose should be explained, and its contents should be concise and accurate. Specialist information or technical descriptions should not be included in the body of the document unless considered crucial to an issue. It is appropriate to include ancillary or lengthy technical information in the appendices.

Environmental issues

The Environmental Protection Authority considers that the following issues are likely to be the most important environmental issues related to this proposal:

Sulphur Dioxide (SO_2) emissions;
fugitive dust emissions;
odorous emissions;
noise emissions;
solid waste discharges and management practices;
liquid waste effluent treatment and discharge to the environment;
groundwater usage and contamination;
transportation of raw materials and finished products.

The CER should include sufficient information to enable the EPA to thoroughly assess the processing plant and its potential environmental impacts. In particular the EPA considers that the proponent should:

provide flow diagrams for the synthetic rutile processing plant that include relevant flow rate and mass balance information;

provide detailed waste management (minimisation, reuse and treatment) strategies; and

identify all known or potential issues that (from experience of the processes elsewhere or in trials) may result in environmental impacts.

As with all industrial proposals, it is important to address:

land use issues:
- alternative sites;
- cadastral information;
- adjacent land uses;
- impact of project on current land uses;
- location of structures to be built on the site;
- provision of services and drainage;

water supply and management issues:
- scheme and groundwater water availability/use;
- groundwater drawdown potential and impacts (eg. salinity or competing uses);
- ground or surface water processing requirements/impacts;

transport issues:
- advantages/disadvantages of transport alternatives;
- mineral concentrate and waste transport alternatives;
- potential social and environmental consequences;

operational management issues:

pollution controls (dust, noise and waste controls);
rehabilitation/decommissioning and final land use;

social issues

impact of project workforce during construction and operations;
impact of project workforce and attendant population of local communities;
impact of project on nearest neighbours to sites;
local benefits; and

any other relevant environmental issues raised during the environmental impact assessment process.

Public participation and consultation

A description should be provided of the public participation and consultation activities undertaken by the proponent and the objectives of those activities. It should be cross referenced with the "environmental issues" section and should clearly indicate how community concerns have been addressed. Where these concerns are dealt with by government agencies or procedures outside the EPA process, these should be noted and referenced.

Monitoring programmes

The proponent should recognise that periodic and long term monitoring is likely to be required for certain aspects of this proposal (eg. waste discharges and rehabilitation) and commit to putting a programme in place to address any such issues.

Environmental management commitments

The commitments being made by the proponent to protect the environment should be clearly stated and separately listed. The list will then be included as an attachment to the Minister for the Environment's environmental conditions if the proposal is found to be acceptable.

Where an environmental problem has the potential to occur, there should be a commitment to rectify it. They should be numbered and take the form:

who will do the work;
what will be done;
when will it be carried out;
to whose satisfaction will it be carried out; and
where it will be carried out (if relevant).

All actionable and auditable commitments made in the body of the CER should be numbered and summarised in this list. Where the EPA considers that the issues covered by commitments can be managed under the Works Approval and Licence conditions of the Environmental Protection Act (eg. noise and dust) these commitments will be identified by the EPA in order to prevent unnecessary duplication of the commitment in the environmental conditions issued by the Minister for the Environment.

APPENDIX 2

Step 4

Send It Off

Your submission must reach the EPA by the closing date, stated in the advertisement announcing the release of the developer's report.

Remember to:

- Print your name and address and the date you make the submission.
- Attach copies of any factual information you wish to provide.
- Give details of the source of any published information you quote.
- Tell the EPA if you are prepared to have all or part of your submission quoted or if you are prepared to be identified in its report on the proposal.

What happens to submissions?

The EPA will notify you that your submission has been received. All submissions are confidential unless you state you want your identity linked to your submission.

Your submission will be read by an EPA assessment officer. The concerns raised in all submissions will be summarised and sent to the developer, who will be asked to respond and perhaps provide further information or modify the proposal to address your concerns.

After the public submission period, the EPA will recommend action to the Minister for Environment based on the assessment of the developer's report, public submissions and any additional information.

Summaries of the number and type of concerns raised will be included in the EPA's report, which will help the Government make decisions about the proposal.

Remember

Don't think that you are only one voice and you won't make a difference. For the EPA's assessment, just one well-reasoned submission which raises a valid concern or offers a constructive suggestion can be very helpful and important.

Each submission is important in its own right, but those submissions that present reasons for concern and offer good information and suggestions are of most use.

Remember that it is equally important to comment on parts of a proposal that are positive or offer new opportunities for local people.

The EPA deals with effects on the physical, biological and social environment.

The Social Impact Unit contributes to the assessment process by encouraging people to become involved and informed and by advising the EPA on the project's effect on people.

For more information, contact

The Social Impact Unit
Ground Floor
197 St Georges Terrace
Perth WA 6000
Telephone (09) 222 9988
Facsimile (09) 321 1473

SOCIAL · IMPACT · UNIT

The Environmental Protection Authority
8th Floor
Westralia Square
38 Mounts Bay Road
Perth WA 6000
Telephone (09) 222 7000
Facsimile (09) 322 1598

The Environmental Assessment Process

MAKE A
DIFFERENCE
BY MAKING A
SUBMISSION

SOCIAL · IMPACT · UNIT

When someone wants to change the way a certain piece of land is used, and that new use may significantly affect the water, air, land, plants and animals, or people nearby, their proposal must be assessed by the Environmental Protection Authority (EPA).

By making a public submission, you can tell the EPA your opinion of the development, contribute knowledge and make suggestions.

Your submission will help the EPA assess the accuracy and suitability of the developer's report on the proposal.

STEP 1

GET A COPY OF THE DEVELOPER'S REPORT

Developers seeking approval for a project must prepare a report for the EPA.

This report:

- describes the project;
- describes the existing environment;
- details the impacts on the environment;
- details the impacts on people; and
- tells how the impacts will be managed.

This report is available from the developer. You may have to pay a small amount to cover production costs. Copies also may be viewed at local libraries and the EPA library.

You can find out more about the report by checking the advertisement placed by the developer in *The West Australian* or local newspapers and the EPA's weekly advertisement in Saturday's *West.*

STEP 2

DECIDE WHAT TO TELL THE EPA

The EPA deals with effects on the physical, biological and social environment.

The Social Impact Unit contributes to the assessment process by encouraging people to become involved and informed and by advising the EPA on the project's effect on people.

While reading the report, ask yourself these questions:

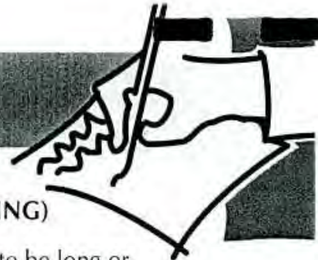
Does the report clearly describe the proposal and the local environment? If not, tell the EPA what is missing.

Does the report cover all the effects of the proposal on the environment and on the people? If you don't think so, tell the EPA what else should be considered.

Is there other information missing from the report? The EPA needs to know if the developer has overlooked anything.

Could the proposal be improved in any way? If so, tell the EPA how.

STEP 3



START WRITING (OR TALKING)

Your submission doesn't need to be long or complex. Your opinions, the reasons for them, and your suggestions about how to improve the proposal are the most important parts.

You might try following one of these different approaches, if you're still unsure:

- Jot down the points you want to make and group them under headings (such as air quality, transport, lifestyle). Use the headings to order your submission.
- Join a group that is making a submission.
- Visit your local library for examples or advice.
- Ask the Social Impact Unit or the EPA for help.

The EPA prefers written reports but you can also put your thoughts on tape.

What makes a good submission?

To make your submission effective, remember the following points while you're writing:

- State clearly your view and your reasons for it.
- Tell how your concerns might be best addressed or give alternatives that might be considered.
- Provide references to any factual data such as scientific reports.
- Use photographs, maps or sketches if possible.
- As you make each point, refer to the relevant section, chapter or recommendation in the developer's report.
- If your submission is long, summarise the major points.

You can make a submission in a language other than English; the EPA will arrange a translation.

The report will summarise the issues, outline the problems and recommend ways to make the proposal environmentally acceptable.

Anybody can appeal against the content or recommendations of an EPA assessment report.

The EPA does not decide whether a project can proceed - it simply provides advice to the Minister for Environment.

The Minister makes the decision.

Before the project can go ahead, the Minister for Environment will set conditions which the developer must meet.

These conditions can cover such issues as die-back control, especially in mining ventures, or the need to seek expert advice on birdlife, as in developments near wetlands.

In setting the conditions, the Minister consults other Ministers and authorities who have an interest in the proposal.

The developer may appeal against Ministerial conditions which, when set, are legally binding.

Environmental management

As part of the assessment process, the EPA may ask the developer to prepare an Environmental Management Plan to deal with long-term environmental impact.

The Minister for Environment also may insist on an EMP as part of the conditions attached to a project.

EMPs can cover such matters as the transport of waste, the management of evaporative ponds and revegetation.

Appeals

Environmental assessment is not only about analysing the ecological impact of a project.

It's also about people.

That's why the EPA's assessment process allows people to appeal to the Minister for Environment against matters which will affect them as well as the environment.

Under the Environmental Protection Act, the public can appeal over:

- Whether a project is assessed formally or informally
- The level of formal assessment (it might be too low)
- The EPA's assessment report and recommendations

The developer also can appeal against conditions that are set on a project.

Appeals must be accompanied by $10 and you have 14 days in which to lodge them.

Separate appeals cover works approvals and licences.

For more information, please contact:

The Environmental Protection Authority
1 Mount Street
PERTH WA 6000

Ph: (09) 222 7000
Fax: (09) 322 1598

Environmental Protection Authority

EPA
AN ENVIRONMENT WORTH PROTECTION

Environmental impact assessment

Western Australia - an environment worth protection

How it works

Any development which affects the environment must be referred to the Environmental Protection Authority.

It's a simple concept for an extremely complex issue. Nevertheless, the EPA strives to make its assessment process as public and as simple as possible.

From septic tanks to coal mines - the community has a role in the environment.

The EPA considers more than 1000 projects a year which come to it from developers, environmentalists, Government departments, local councils - anybody with an interest in the project.

Sometimes, the Authority's five members - or board of management - might even "call in" a project.

How ever they get to the EPA, projects are assessed according to their environmental impact.

'Filtering'

This initial assessment is called "filtering" where environmental officers with long experience advise the EPA chairman which projects need close scrutiny and which ones don't.

Of course, some projects which come to the EPA do not need assessing because their environmental impact is minimal.

The level of assessment set by the EPA will depend on the environmental impact.

For a minor subdivision, for example, with little environmental impact, the EPA's assessment may be limited to seeking details of the proposal and providing advice to the developer, local council or Government agency on steps to manage any problems.

This advice is publicly available at the EPA's Information Centre.

But a major new industry that is likely to have a significant environmental impact would be assessed "formally", in which case the company would be asked to do an environmental impact statement.

Formal assessment

The EPA's assessment of projects is aimed at determining whether they are environmentally acceptable.

To that end, the EPA will provide advice on what developers should do to ensure the environment is protected.

The Minister for Environment sets legally binding conditions on projects and, very occasionally, these conditions may say a project is environmentally unacceptable.

In Western Australia, the three levels of formal assessment are:

- Consultative Environmental Review
- Public Environmental Review
- Environmental Review and Management Programme.

The CER is the lowest level of formal assessment and the ERMP is the highest.

By appeal, anybody can ask for the level of assessment to be upgraded.

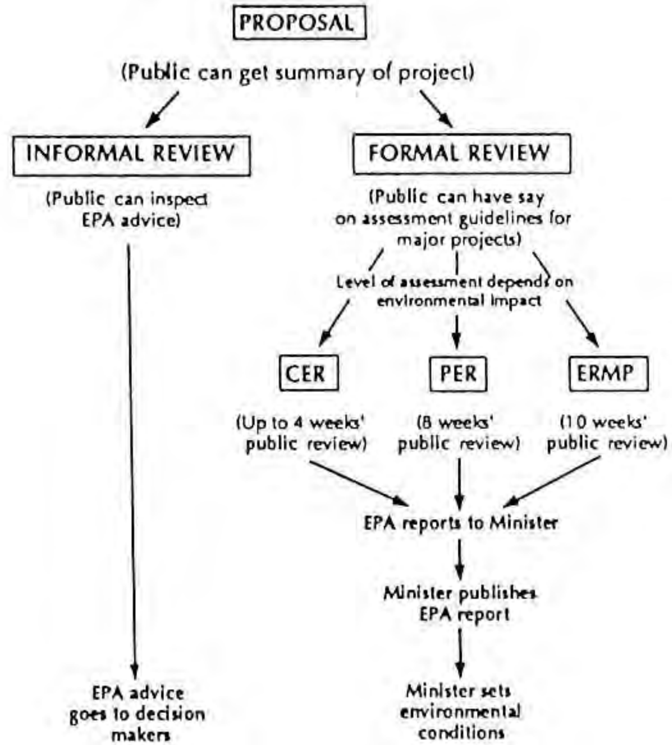
With "formal" assessments, the EPA will ask the developer - known as the proponent - to provide detailed information about the project.

The Authority will also provide the developer with guidelines for preparing the CER, PER or ERMP document.

The public can comment on guidelines for high-level assessments, or ERMPs.

For this assessment document, the developer must explain the project and outline its environmental impact and how that impact will be managed.

EPA project assessment



Public submissions

Reports by developers are made public for up to 10 weeks during which submissions can be made.

For some projects, the EPA may arrange public meetings to discuss the issues and provide greater opportunity for public debate.

After the public has had a say, the EPA then considers the proposal, including the public submissions.

Submissions are confidential though the proponent will be asked to comment on the issues they raise.

The EPA also seeks advice from independent experts, including officers from Government departments and private consultants.

When the assessment is finished, the EPA prepares a report which will say whether the project is environmentally acceptable.

APPENDIX 3

GROUNDWATER RESOURCE EVALUATION OF THE YARRAGADEE FORMATION TO MEET THE PROCESS WATER SUPPLY DEMANDS OF THE PROPOSED SECOND SYNTHETIC RUTILE PLANT AT CAPEL, WESTERN AUSTRALIA

for

Westralian Sands Limited

DAMES & MOORE

Dames & Moore Job No. 14365-030-074

June 1992

DAMES & MOORE

SOUTH SHORE CENTRE, 85 THE ESPLANADE SOUTH PERTH, WA 6151
TELEPHONE 09-367 8055 FACSIMILE 09-367 6780

29 June 1992

Westralian Sands Ltd
PO Box 96
CAPEL WA 6271

Attention: Mr B. McLoughlin

Dear Sir,

GROUNDWATER RESOURCE EVALUATION OF THE YARRAGADEE FORMATION TO MEET THE PROCESS WATER SUPPLY DEMANDS OF THE PROPOSED SECOND SYNTHETIC RUTILE PLANT AT CAPEL, WESTERN AUSTRALIA

We have pleasure in forwarding one bound and two unbound copies of our final report concerning the availability of groundwater to meet the process water demands of the proposed Synthetic Rutile Plant at Capel. Should you have any queries please do not hesitate to contact either Marcus Chandler or the undersigned.

May we thank you for giving Dames & Moore the opportunity to work on this interesting project and look forward to continuing to assist Westralian Sands Ltd in the future.

Yours faithfully
DAMES & MOORE

R.J. McGowan
Consultant-in-Charge
Hazardous Waste Management

MSC:sor/14365-030-074/DK:22-4223

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GROUNDWATER RESOURCE EVALUATION OF THE YARRAGADEE FORMATION TO MEET THE PROCESS WATER SUPPLY DEMANDS OF THE PROPOSED SECOND SYNTHETIC RUTILE PLANT AT CAPEL, WESTERN AUSTRALIA

1.0 INTRODUCTION

Westralian Sands Limited (WSL) are currently preparing a Consultative Environmental Review (CER) for the proposed second Synthetic Rutile (SR) Plant at Capel, Western Australia. As part of the review process, a groundwater resource evaluation is necessary in support of an increase in the licensed groundwater abstraction from 2.7×10^6kL/annum to 4.7×10^6kL/annum. The increased groundwater abstraction is required to meet the additional process water demand of the new SR Plant scheduled for completion in 1995. The location of the SR Plant in relation to Cape and other major users is shown on Figure 1.

Dames & Moore were commissioned by WSL under Purchase Order 156322 dated 16 June 1992, to undertake an evaluation of the available groundwater resources with particular reference to the Yarragadee Formation in the Capel area. The groundwater resources of the superficial formation and Leederville Formation have not been assessed at this stage. This is due to large abstraction already taking place in the superficial formations and potential future development of the Leederville Formation in this area for public water supply.

2.0 PURPOSE AND SCOPE

The key purposes of the assessment are to:

- evaluate the throughflow in the Yarragadee Formation and assess the resources available to meet the additional demand;
- use a computer model to assess the impact of increased abstraction on the groundwater resource and existing users such as the Water Authority at Capel;
- assess the most cost-effective method for increasing groundwater abstraction by either increased bore pump capacity or an increased number of bores;
- optimise the location of additional bores to minimise the impact on nearby users; and
- develop a preliminary groundwater monitoring and management programme.

3.0 HYDROGEOLOGY OF THE YARRAGADEE FORMATION

3.1 AQUIFER CHARACTERISTICS

The Yarragadee Formation occurs throughout the Bunbury Trough and is unconformably overlain by the Leederville Formation, except where the Leederville Formation has been removed by erosion. The formation thins northward from a thickness of 1,115m at the Quindalup Line (Wharton, 1981) to 196m in Bunbury (Wharton, 1979). The thinning is due to erosion of the upper surface. In the Capel area, the Yarragadee Formation is approximately 800 metres thick.

The formation comprises interbedded sand, grey carbonaceous shale and siltstone. In the upper 200m to 400m, sands account for less than 25% of the total thickness, while the basal portion is predominantly sand. The sand consists primarily of medium to coarse grained weakly consolidated pale grey quartz sandstone. In the Capel area a significant proportion of the upper sequence has been eroded.

On the basis of pumping test results for the Yarragadee Formation, hydraulic conductivity values vary between 18 to 25m/day with an average aquifer storage coefficient of 5×10^{-4}, indicative of confined conditions.

3.2 GROUNDWATER FLOW

Figure 2 shows the potentiometric surface of the Yarragadee Formation in the Capel area for the period June 1983 and April/June 1991. The base of the freshwater flow system is at a depth of approximately 1,000m in the Quindalup Line bores and 800m in the Boyanup Line bores. The base is defined as the interface with saline/hypersaline groundwater and coincides approximately with the contact between the Yarragadee Formation and the underlying Cockleshell Gully Formation.

On the basis of work completed on the Boyanup (Smith 1982) and Quindalup Line (Wharton 1981), there is a net downward head potential in the Yarragadee Formation. In addition, the rate of groundwater throughflow is much higher in the transmissive lower sandy section of the formation than the relatively poorly permeable upper section.

The groundwater isopotential contours (Figure 2) indicate that groundwater flow is predominantly northwest across the area. This infers the Blackwood Plateau south of the Quindalup Line is a major recharge zone. Additional recharge is also considered to be taking place by downward leakage from the Leederville Formation and superficial formations.

Natural seasonal fluctuations in water level vary between approximately 0.5 and 1.0m. Discharge from the Yarragadee Formation is taking place either directly to the sea or through the overlying superficial formations.

The throughflow (Q) in the Yarragadee Formation across the 10m potentiometric head groundwater contour on Figure 2 can be calculated from the following equation:

$$Q = Kbiw$$

where:
- K = hydraulic conductivity of the sandy sections of aquifer
- b = average thickness of sand sections
- i = average hydraulic gradient of the Yarragadee Formation
- w = width of the section.

Using a hydraulic conductivity (K) of 20m/day, an average thickness (b) of 600m of sand, and a hydraulic gradient of 3.0×10^{-4}, the throughflow across a 17km length (l) of the 10m potentiometric head groundwater contour is:

$$Q = 20 \times 600 \times 3 \times 10^{-4} \times 17{,}000$$

$$= 61{,}200m^3/day\ (22.34 \times 106m^3\ year).$$

The 17km length represents the estimated radius of influence of groundwater abstraction from the Yarragadee Formation in the Capel area.

3.3 GROUNDWATER QUALITY

The salinity of the groundwater in the Yarragadee Formation underlying Capel is less than 500mg/L based on salinity concentrations estimated from long normal resistivity logs. It increases rapidly near the base of the Yarragadee Formation where it overlies the Cockleshell Gully Formation.

The groundwater tends to be either a sodium chloride or sodium bicarbonate type with a near neutral pH.

4.0 CURRENT ABSTRACTION FROM THE YARRAGADEE FORMATION

4.1 SR PLANT USAGE

The current process water demands of the existing SR Plant total 2.7 x 10^6kL/annum. This is currently met by the pumping of 5 bores (J7100 to J7104). Construction details of these bores is summarised in Table 1. Details are also given for bore NCM3, which provides water to the North Capel mining operation. Details of pump types, motor sizes, pump depths and current/peak flow rates are given in Table 2. On the basis of pumping 322 days per year, the current borefield is able to meet the present demand. However, there is no standby capacity to maintain borefield output if there is a pump or bore failure. For the remainder of the year the SR Plant is shutdown for routine maintenance and overhaul.

TABLE 1

BORE CONSTRUCTION DETAILS
NORTH CAPEL AND SYNTHETIC RUTILE PLANT

Bore No.	*Coordinates*		*Date Drilled*	*Total Depth (m)*	*Casing*			*Screen*			*Yield Airlift (m^3/day)*	*Production Rate (m^3/day)*
	Northing	*Easting*			*Depth Interval (m)*	*Type*	*ID (mm)*	*Depth Interval (m)*	*Type*	*ID (mm)*		
NCM3	6289421	368002	3/1974	140	0-128.5	Steel	204	128.5-140	Tel.* Screen	219	1,966	2,160
J7100	6291238	368618	2/1977	159	0-86	Steel	204	86-159	Slotted PVC	140	2,730	2,160
J7101	6291547	368949	3/1978	160	0-96	Steel	204	96-160	Slotted PVC	140	3,280	2,160
J7102	6290644	368828	7/1986	170	0-70 70-150	Steel Steel	254 204	146-170	Tel. Screen	200	-	3,600
J7103	6290499	368443	8/1986	170	0-70 70-150	Steel Steel	254 204	150-170	Tel. Screen	200	-	3,360
J7104	6290908	368643	8/1963	151	0-140	PVC	140	140-152	Tel. Screen	150	3,600	2,160

Note: Tel. - Telescopic.

TABLE 2

PUMP DETAILS
NORTH CAPEL AND SYNTHETIC RUTILE PLANT

Bore No.	*Pump*	*Motor (Hp)*	*Pump Depth (m)*	*Flow Rate (m^3/hr)*	
				Current (June)	*Peak*
NCM3	6 Stage Metcalf 75MM 1.8 submersible	50	65	90	90
J7100	8 Stage Metcalf bore pump	30	46	90	}
J7101	Southern Cross submersible	40	30	90	}
J7102	Southern Cross submersible	50	60	150	} 360 All bores operating
J7103	Southern Cross submersible	50	60	140	}
J7104	8 Stage Metcalf bore pump	30	32	90	}

4.2 MAJOR USERS

Figure 1 shows the location of the existing licensed groundwater users and town water supplies in the Capel area. The total annual allocation from all sources for 1991 was 7.03 x 10^6kL. The details are summarised in Table 3.

TABLE 3

CURRENT ABSTRACTION FROM THE YARRAGADEE FORMATION

Groundwater Licence No.	*Owner*	*Location*	*Purpose*	*Allocation (kL/year)*
31427	WSL	Loc. 3719 Capel	Industrial	760,000
34534	WSL	Loc. 1056, 3345, Pt 4130	Industrial	2,700,000
34535	WSL	61 Jenkins Road, Capel	Industrial	1,100,000
35490	AMC	Loc. 2039, Capel	Industrial	2,200,000
-	WAWA	Capel Town Water Supply	Public Use	240,000*
-	WAWA	Peppermint Grove Town Water Supply	Public Use	30,000*

Notes:
WSL - Westralian Sands Limited.
AMC - AMC Minerals Sands Limited.
WAWA - Water Authority of Western Australia.
* - 1991 actual abstraction.

4.2.1 Impact of Current Users on Groundwater Flow

On the basis of regular water level monitoring in boreholes along the Boyanup and Quindalup lines, there has been a regional decline in water levels of 1.2 to 1.5m during the 8 year period between June 1983 to June 1991. The decline in water levels and regional groundwater flow is probably due to the development of Water Authority and private borefields for mineral processing and public water supply in the Capel area. Drawdowns are greater in the vicinity of the borefields with seasonal fluctuations in the range 2 to 4m. Due to the nature of the aquifer, drawdowns outside the licensees property on which the borefields are located are generally less than 1.5m.

5.0 POTENTIAL FOR ADDITIONAL ABSTRACTION FROM THE YARRAGADEE FORMATION

5.1 SECOND SR PLANT WATER SUPPLY REQUIREMENTS

On the basis of current design parameters, the second SR Plant will require an additional 2 x 10^6kL/annum of process water. Assuming pumping for 322 days per year, this is equivalent to a rate of approximately 260kL/hour.

By modifying the existing depth settings, motors and number of pump stages, the existing bore may be capable of maintaining the following bore yields.

Bore	*Current Yield (kL/hr)*	*Potential Yield (kL/hr)*	*Increase (kL/hr)*
J7102	150	230	80
J7103	140	220	80
TOTAL	290	450	160

During construction of the new SR Plant, it will be necessary to relocate J7102 and the above calculation assumes the pumpage from the replacement bore will be similar to that of the existing bore. The potential increase in yield from the existing bores by increasing pumping rates and pump settings is therefore insufficient to meet the anticipated demand and further bores are required.

Based on the throughflow calculations determined in Section 3.2 and the existing abstraction in the Capel area, the following surplus throughflow is available for exploitation based on total annual flows:

	kL/d
Throughflow across the 10m potentiometric contour	61,000
Current abstraction from the Yarragadee Formation	19,300
Surplus throughflow	41,700
Additional water supply requirements for second SR Plant (2×10^6kL/annum)	5,500
Surplus throughflow for future allocation after construction of second SR Plant	36,200

5.2 FLOW MODELLING OF ADDITIONAL GROUNDWATER ABSTRACTION

An analytical groundwater model has been used to evaluate the impact of current and future groundwater abstraction from the Yarragadee Formation assuming development of the second SR Plant.

5.2.1 Model Layout and Parameter

Figure 3 shows the model layout in relation to the area of interest and details of nearby borefields. The model assumes a uniform porous non-leaky artesian aquifer with constant thickness. The 17km x 23km model grid covers the same area as is shown on Figure 1. The model was run for a simulated period of 365 days with a hydraulic conductivity of 20m/day, effective aquifer thickness of 600m and a confined storage coefficient of 2×10^4. The six pumping nodes represent the current users drawing from the Yarragadee Formation in the Capel area. For the purposes of the modelling the daily abstraction is equivalent to the annual licence abstraction divided by a 322 day pumping year. Near steady state conditions are achieved during the first year of simulation.

5.2.2 Results of Modelling

The model was run with the following pumping scenarios:

- Model 1 - at current (1992) licence allocations; and
- Model 2 - same as Model 1 with an increased allocation for the SR Plant from 2.7×10^6kL/annum to 4.7×10^6kL/annum.

Figures 4 and 5 show the resultant drawdown cone for Models 1 and 2 respectively. Details of drawdown in individual nodes is given in Appendix A.

Model 1

At the current rates of abstraction regional groundwater levels decline approximately 1.6m in the vicinity of AMC Capel, 1.8m within 300 metres of the existing SR Plant and 1m within 500m of Capel. The water levels at Capel are affected by interference pumping from the adjacent AMC and WSL borefields. These results are in good agreement with the long-term observation data compiled by the Water Authority for 1983 and 1991.

Model 2

By increasing the current abstraction rate at the Synthetic Rutile Plant from 2.7 x 10^6kL to 4.7 x 10^6kL the drawdown cone shows limited further development. Regional water levels decline a further 0.2m and water levels decline an additional 0.4m within 500m of Capel.

Local groundwater levels near the SR Plant would decline a further 1m and the drawdown cone between WSL operations at Jenkins Road and the SR Plant would coalesce as shown on Figure 5.

5.3 PREDICTED IMPACT OF INCREASED ABSTRACTION

Increasing the licence allocation for the WSL SR Plant at Capel, from 2.7 x 10^6kL/annum to 4.7 x 10^6kL/annum, will result in an increase in regional drawdown of approximately 0.2m at a radial distance of 7km from the borefield. On the basis of the preliminary computer modelling so far completed, the following increased average drawdowns are expected for existing users in the Capel area:

Groundwater Licence No.	*Owner*	*Increased Drawdown (m)*
31427	WSL	0.5
34534	WSL	1.1
34535	WSL	0.5
35490	AMC	0.3
-	Capel TWS	0.4
-	Peppermint Grove TWS	0.2

Due to the nature of the model used for this study, incorporating a relatively coarse regional mesh, the increased drawdowns within the SR Plant site cannot be determined. Further modelling is necessary to evaluate local interference effects and optimise the depth setting of pumps to meet the increased demand for process water from the existing and proposed borefields at the SR Plant.

6.0 GROUNDWATER MANAGEMENT

To maintain the highest possible quality and yield from the existing and proposed borefield, an effective groundwater management programme is necessary. This relates not only to the final monitoring and management programme selected by WSL, but also the layout and equipping of the proposed borefield.

6.1 PROPOSED BOREFIELD LAYOUT

To accommodate the second SR Plant, WSL propose to relocate bore J7102 approximately 100m northeast of its present position. A second bore is proposed 20m west of the eastern site boundary, approximately 160m south of the Yeardy Road alignment. On the basis of the available data a third bore is recommended north of the SR Plant and south of Cable Mine Road. The final position of this bore will depend on several factors including access and power reticulation. This bore would provide a standby capacity to the borefield in the case of pump or bore failure. The new bores should be constructed to depths varying between 250 and 400m. This would further minimise the effects on existing users and adjacent WSL bores. The bores should be constructed and tested during the plant shutdown phase to permit the completion of meaningful pumping tests prior to commissioning.

6.2 PRELIMINARY MONITORING AND MANAGEMENT PROGRAMME

The design of the groundwater monitoring and borefield management programme cannot be finalised until the location of the production bores and pump settings has been determined. The groundwater monitoring and borefield management programme should make provision for the following:

- o all production bores should be equipped with inline flow meters capable of recording aggregate discharge and flow rate and have access tubes for direct water level measurement;

- the depth to water, temperature, pH and electrical conductivity of the groundwater in all production bores should be recorded monthly, together with aggregate discharge;
- a record should be kept of whether the bore is pumping at the time of measurement. Depth to water measurements should always be taken at the same phase of pumping, either just before the pump is switched off or just before it is switched on;
- the discharge water level, temperature, pH and electrical conductivity results should be reviewed after three months to confirm the aquifer is performing satisfactory without deleterious effects. This will allow a reassessment of aquifer parameters and revision (if necessary) of the pumping schedules; and
- after three months, one litre water samples should be collected in clear screw topped polyurethane bottles from each bore and submitted for major ion analysis to enable a check that the water quality is not deteriorating.

7.0 CONCLUSIONS

1. There are sufficient groundwater resources available in the Yarragadee Formation to meet the additional process water demand of the SR Plant.

2. Abstraction of an additional 2×10^6kL/annum of groundwater will leave an estimated 13×10^6kL/annum of groundwater throughflow to satisfy the demands of future projects.

3. On the basis of the modelling completed during this study, an increase in the licensed abstraction to 4.7×10^6kL/annum, provided it is drawn from the deeper portions of the aquifer, will increase drawdowns by less than 0.5m in the Capel and Peppermint Grove TWS bores, by 0.4m at AMC Capel, and between 0.5 and 1.1m at adjacent WSL operations.

4. No other detrimental impacts on groundwater flow or water quality are anticipated.

8.0 RECOMMENDATIONS

1. Further work is required to determine the optimum position of replacement/new bores on the SR Plant site to meet the additional process water demand and calculate the most appropriate depth settings for the existing and proposed bore pumps.

2. The production bore monitoring data that was not available for this assessment should be reviewed at the earliest opportunity.

* * *

Respectfully submitted
DAMES & MOORE

Marcus S Chandler

M.S. Chandler
Senior Hydrogeologist

MSC:sor/14365-030-074/DK:22-4223

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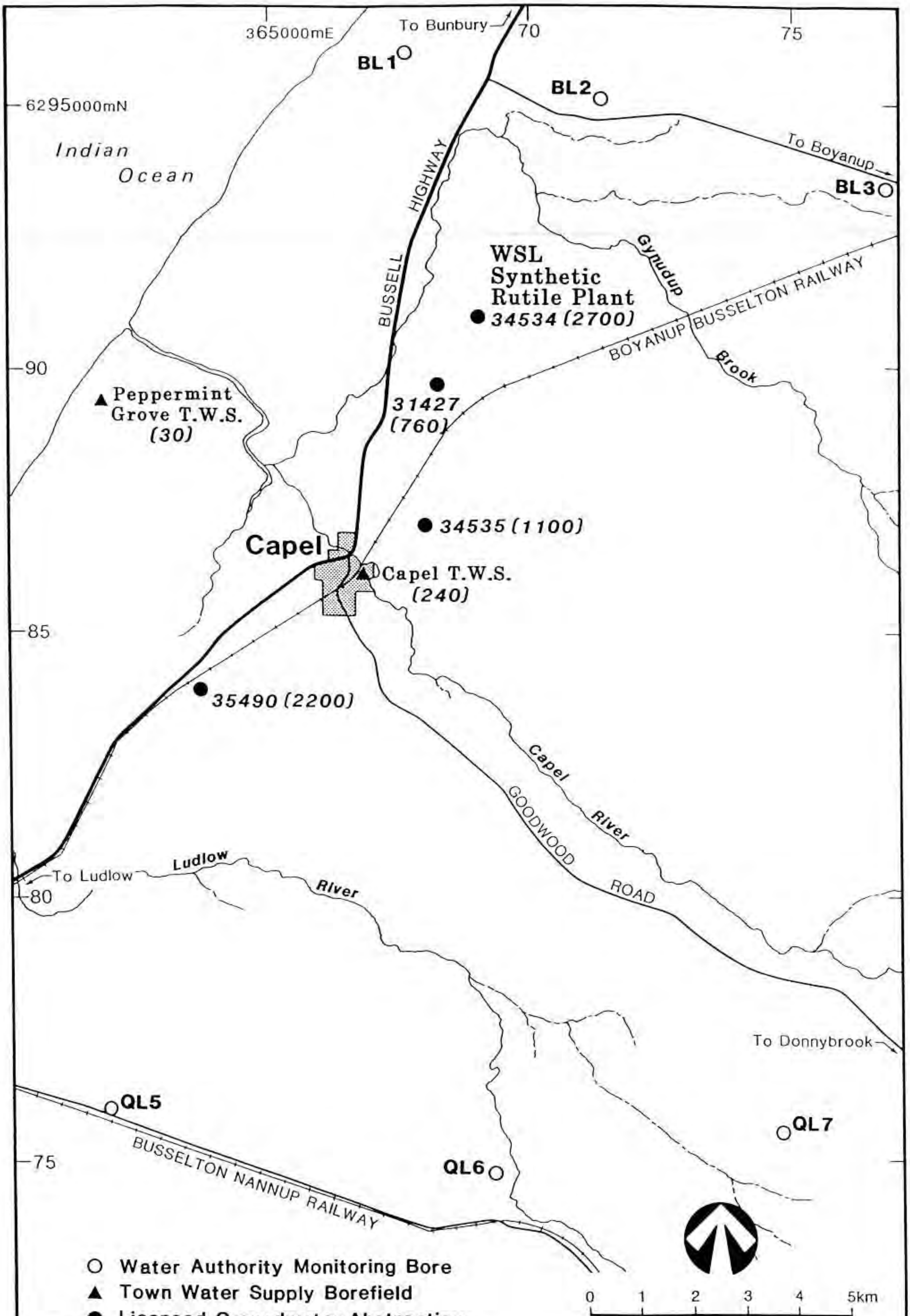
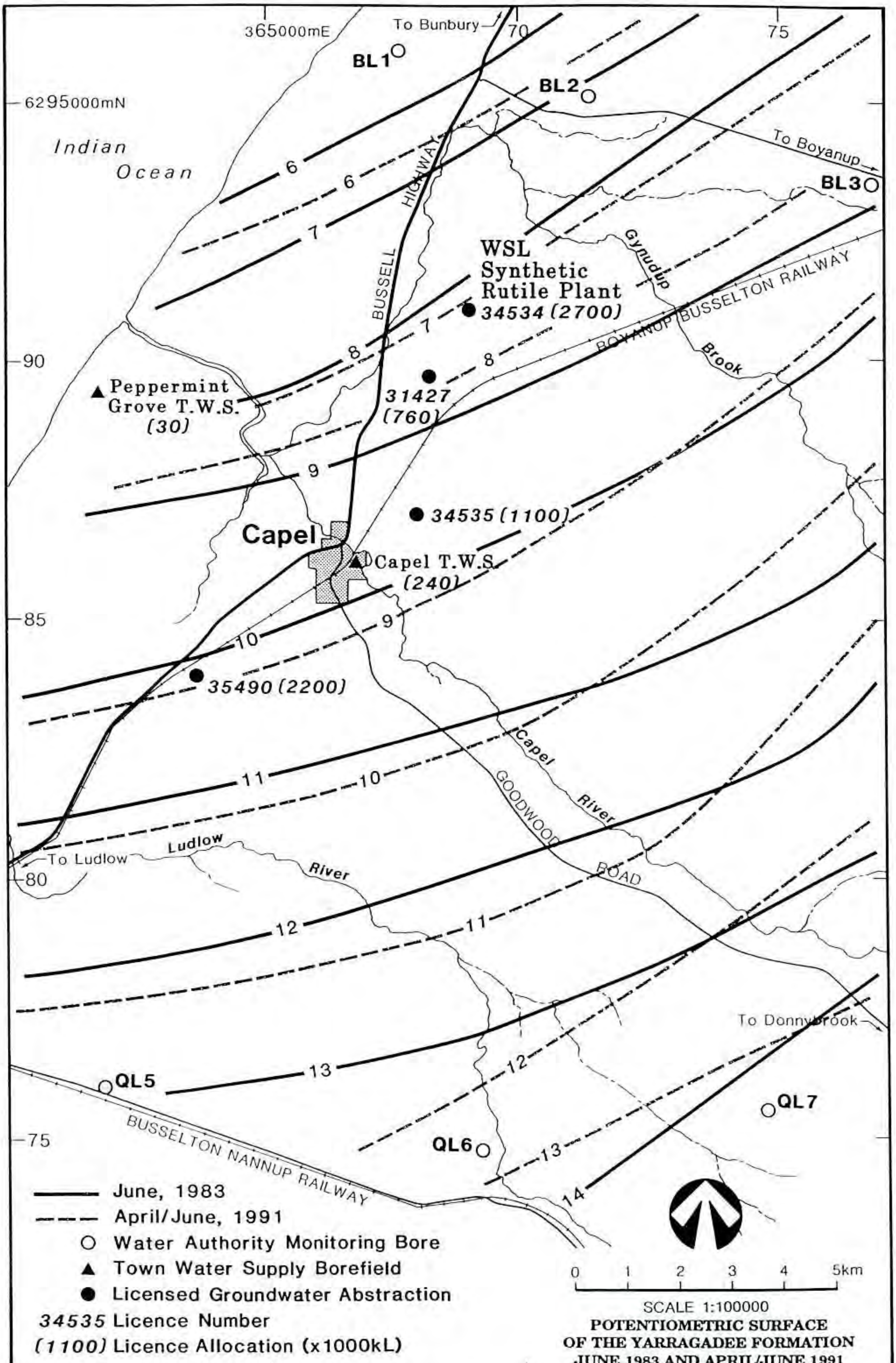
Figures



LOCALITY PLAN AND DETAILS OF CURRENT ABSTRACTION FROM THE YARRAGADEE FORMATION

JOB No. 14385-022-074		DATE
PREPARED BY	MSC	22/06/92
APPROVED BY	[signature]	26/6/92

FIGURE 1
DAMES & MOORE

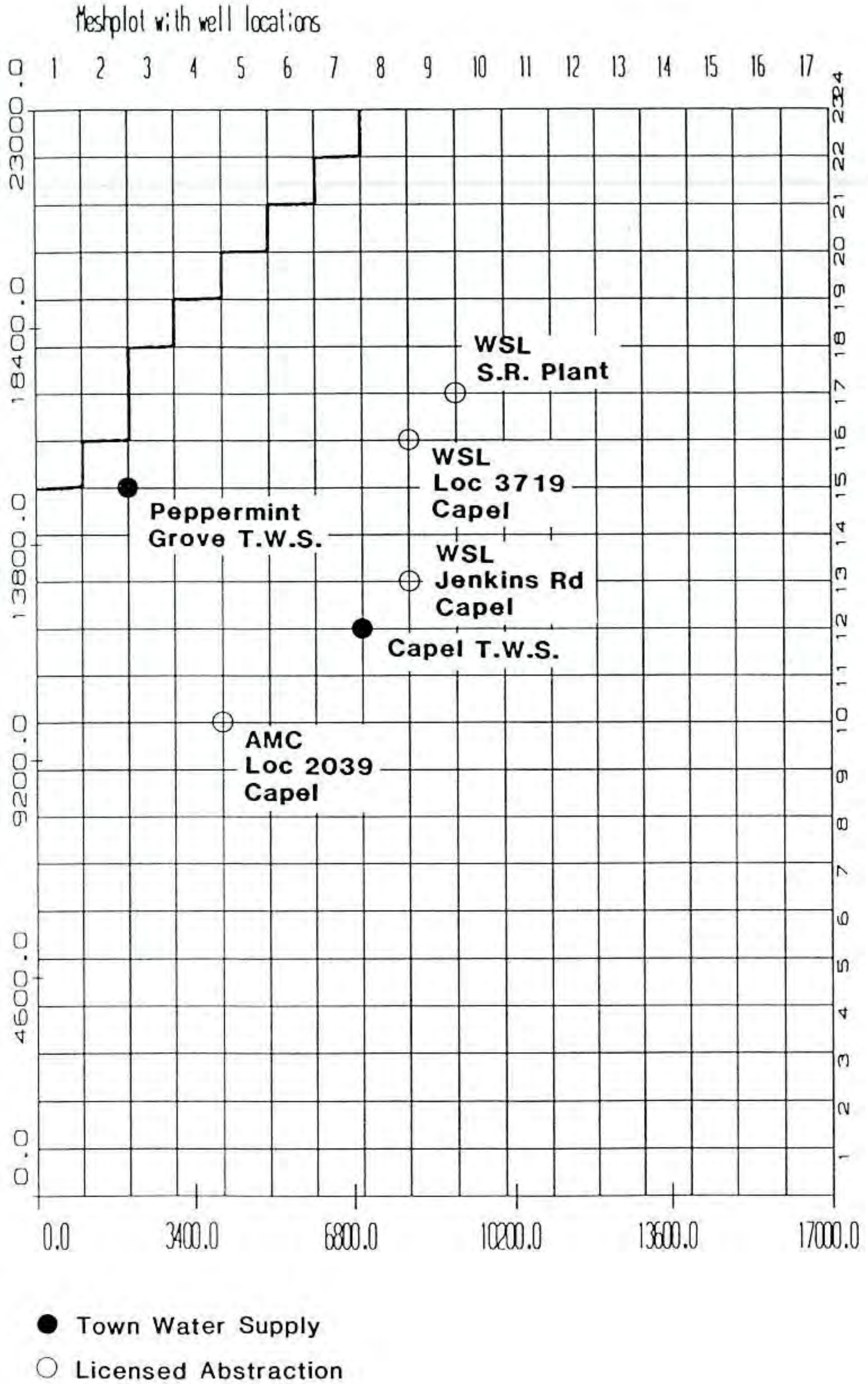


POTENTIOMETRIC SURFACE OF THE YARRAGADEE FORMATION JUNE 1983 AND APRIL/JUNE 1991

JOB No. 14385-022-074		DATE
PREPARED BY	MSC	22/06/92
APPROVED BY	[signature]	26/6/92

FIGURE 2

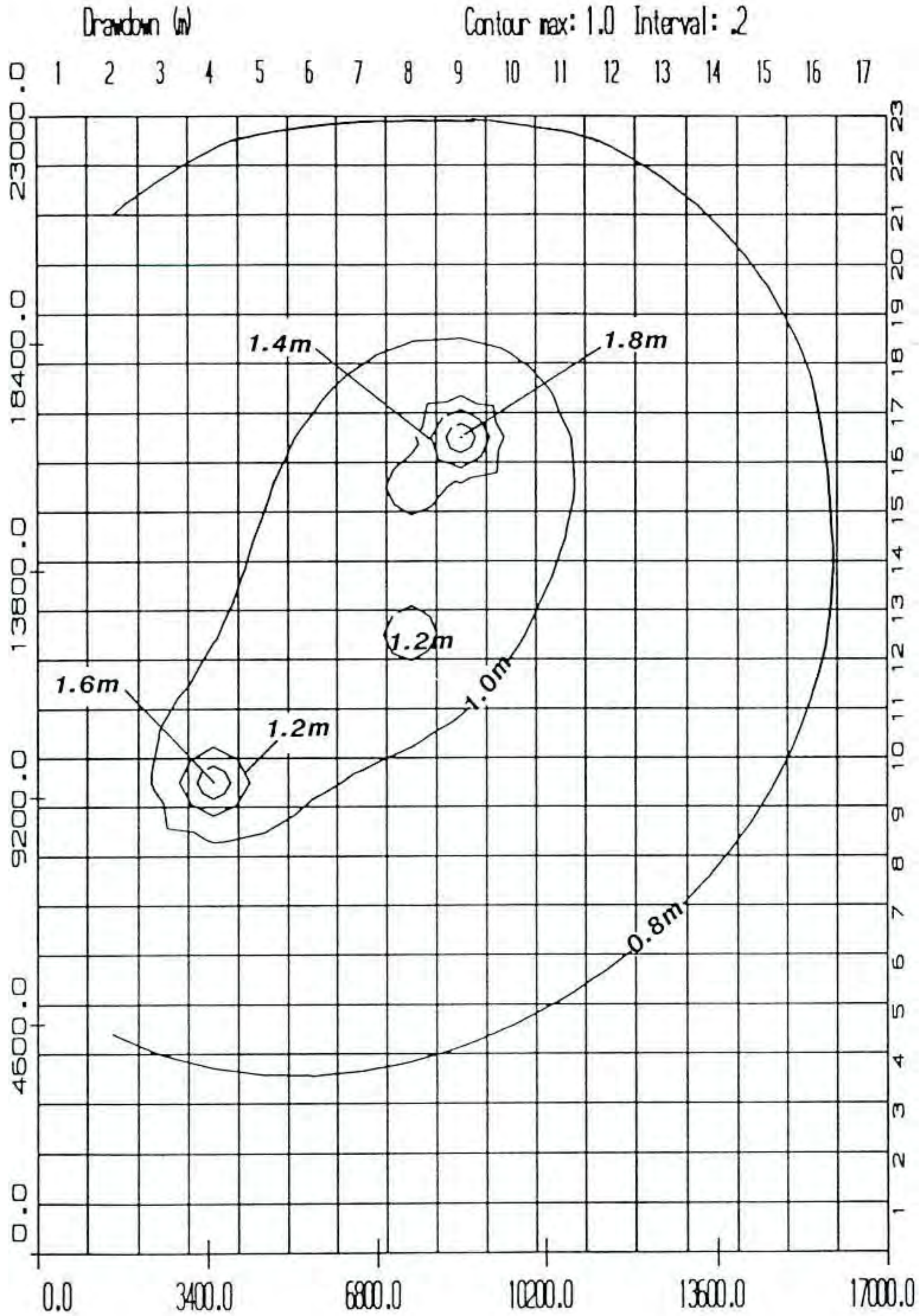
DAMES & MOORE



COMPUTER SIMULATION MESHPLOT WITH WELL LOCATIONS

JOB No. 14385-022-074		DATE
PREPARED BY	MSC	24/06/92
APPROVED BY	[signature]	26/6/92

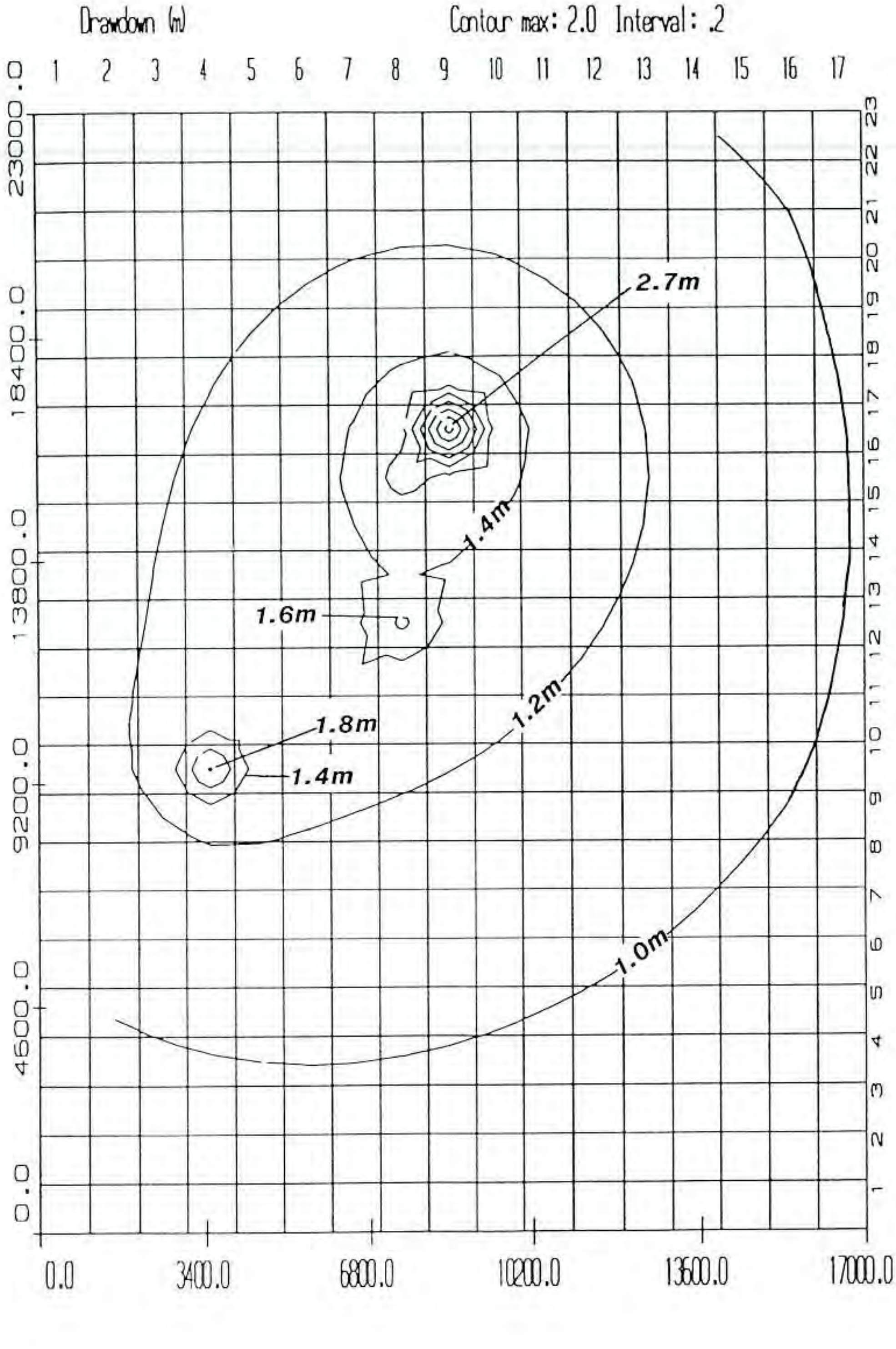
FIGURE 3
DAMES & MOORE



DRAWDOWN CONE AFTER 365 DAYS AT 1992 LICENCE ALLOCATIONS (SR PLANT PUMPAGE = 2.7 x 10-⁶KL)

JOB No. 14385-022-074		DATE
PREPARED BY	MSC	24/06/92
APPROVED BY	[signature]	26/6/92

FIGURE 4
DAMES & MOORE



DRAWDOWN CONE AFTER 365 DAYS
AT 1992 LICENCE ALLOCATIONS AND INCREASED PRODUCTION
(SR PLANT PUMPAGE = 4.7 x 10^6KL)

JOB No. 14385-022-074		DATE
PREPARED BY	MSC	24/06/92
APPROVED BY	[signature]	26/6/92

FIGURE 5
DAMES & MOORE

Appendix A

APPENDIX A

PREDICTED DRAWDOWNS FROM GROUNDWATER MODELLING

AQUIFER TRANSMISSIVITY [M.SQ./DAY]= 12000.0
AQUIFER STORATIVITY (DIM)= 0.00
NO. OF COLUMNS= 17
NO. OF ROWS= 23
GRID SPACING [M.]= 1000.0
NO. OF WELLS= 6

XWELL [M.]= 2000
YWELL [M.]= 15000
WELL DISCHARGE [CU.M./DAY]= 82.0
TIME(DAY)= 365.0

XWELL [M.]= 7000
YWELL [M.]= 12000
WELL DISCHARGE [CU.M./DAY]= 660.0
TIME(DAY)= 365.0

XWELL [M.]= 8000
YWELL [M.]= 16000
WELL DISCHARGE [CU.M./DAY]= 2080.0
TIME(DAY)= 365.0

XWELL [M.]= 9000
YWELL [M.]= 17000
WELL DISCHARGE [CU.M./DAY]= 7400.0
TIME(DAY)= 365.0

XWELL [M.]= 8000
YWELL [M.]= 13000
WELL DISCHARGE [CU.M./DAY]= 3014.0
TIME(DAY)= 365.0

XWELL [M.]= 4000
YWELL [M.]= 10000
WELL DISCHARGE [CU.M./DAY]= 6000.0
TIME(DAY)= 365.0

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
ROW = 1:	0.71	0.72	0.72	0.73	0.73	0.73	0.73	0.73	0.72	0.72	0.71	0.70	0.70	0.69	0.68	0.67	0.66
ROW = 2:	0.73	0.73	0.74	0.75	0.75	0.75	0.75	0.75	0.74	0.74	0.73	0.72	0.71	0.70	0.69	0.68	0.67
ROW = 3:	0.75	0.76	0.76	0.77	0.77	0.77	0.77	0.77	0.76	0.76	0.75	0.74	0.73	0.72	0.71	0.70	0.69
ROW = 4:	0.77	0.78	0.79	0.79	0.80	0.80	0.80	0.79	0.78	0.78	0.77	0.76	0.75	0.73	0.72	0.71	0.70
ROW = 5:	0.79	0.80	0.81	0.82	0.83	0.83	0.82	0.82	0.81	0.80	0.79	0.78	0.76	0.75	0.74	0.72	0.71
ROW = 6:	0.81	0.83	0.84	0.85	0.86	0.86	0.85	0.84	0.83	0.82	0.81	0.79	0.78	0.77	0.75	0.74	0.72
ROW = 7:	0.84	0.86	0.88	0.89	0.90	0.89	0.89	0.87	0.86	0.85	0.83	0.81	0.80	0.78	0.76	0.75	0.73
ROW = 8:	0.86	0.89	0.92	0.94	0.94	0.93	0.92	0.91	0.89	0.87	0.85	0.84	0.82	0.80	0.78	0.76	0.74
ROW = 9:	0.88	0.92	0.97	1.02	1.00	0.98	0.96	0.94	0.92	0.90	0.88	0.86	0.83	0.81	0.79	0.77	0.75
ROW =10:	0.90	0.95	1.02	1.58	1.05	1.01	0.99	0.97	0.95	0.93	0.90	0.88	0.85	0.83	0.81	0.78	0.76
ROW =11:	0.90	0.95	1.01	1.05	1.05	1.03	1.03	1.01	0.99	0.96	0.93	0.90	0.87	0.84	0.82	0.79	0.77
ROW =12:	0.90	0.94	0.98	1.02	1.03	1.05	1.12	1.06	1.02	0.99	0.95	0.92	0.88	0.85	0.83	0.80	0.78
ROW =13:	0.90	0.93	0.97	1.00	1.02	1.05	1.08	1.35	1.06	1.01	0.97	0.93	0.90	0.86	0.84	0.81	0.78
ROW =14:	0.89	0.92	0.95	0.98	1.02	1.05	1.08	1.10	1.07	1.03	0.99	0.95	0.91	0.87	0.84	0.81	0.79
ROW =15:	0.88	0.92	0.94	0.97	1.01	1.04	1.08	1.11	1.10	1.06	1.00	0.96	0.91	0.88	0.84	0.81	0.79
ROW =16:	0.87	0.90	0.93	0.96	0.99	1.03	1.09	1.32	1.15	1.09	1.02	0.96	0.91	0.88	0.84	0.81	0.79
ROW =17:	0.86	0.88	0.91	0.94	0.97	1.01	1.07	1.14	1.80	1.10	1.01	0.95	0.91	0.87	0.84	0.81	0.78
ROW =18:	0.84	0.87	0.89	0.92	0.95	0.98	1.02	1.07	1.09	1.05	0.99	0.94	0.89	0.86	0.83	0.80	0.78
ROW =19:	0.83	0.85	0.87	0.89	0.92	0.95	0.97	1.00	1.00	0.98	0.95	0.91	0.88	0.84	[illegible]	0.79	0.77
ROW =20:	0.81	0.83	0.85	0.87	0.89	0.91	0.93	0.94	0.94	0.93	0.91	0.88	0.85	0.83	0.80	0.78	0.76
ROW =21:	0.79	0.81	0.83	0.84	0.86	0.88	0.89	0.89	0.89	0.88	0.87	0.85	0.83	0.81	0.79	0.77	0.75
ROW =22:	0.78	0.79	0.81	0.82	0.83	0.84	0.85	0.86	0.86	0.85	0.84	0.82	0.81	0.79	0.77	0.75	0.74
ROW =23:	0.76	0.77	0.78	0.80	0.81	0.82	0.82	0.82	0.82	0.82	0.81	0.80	0.78	0.77	[illegible]	0.74	0.72

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AQUIFER STORATIVITY (DIM)= 0,.00
NO. OF COLUMNS= 17
NO. OF ROWS= 23
GRID SPACING [M.]= 1000.0
NO. OF WELLS= 6

XWELL [M.]= 2000
YWELL [M.]= 15000
WELL DISCHARGE [CU.M./DAY]= 82.0
TIME(DAY)= 365.0

XWELL [M.]= 7000
YWELL [M.]= 12000
WELL DISCHARGE [CU.M./DAY]= 660.0
TIME(DAY)= 365.0

XWELL [M.]= 8000
YWELL [M.]= 16000
WELL DISCHARGE [CU.M./DAY]= 2080.0
TIME(DAY)= 365.0

XWELL [M.]= 9000
YWELL [M.]= 17000
WELL DISCHARGE [CU.M./DAY]= 12880.0
TIME(DAY)= 365.0

XWELL [M.]= 8000
YWELL [M.]= 13000
WELL DISCHARGE [CU.M./DAY]= 3014.0
TIME(DAY)= 365.0

XWELL [M.]= 4000
YWELL [M.]= 10000
WELL DISCHARGE [CU.M./DAY]= 6000.0
TIME(DAY)= 365.0

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
ROW = 1:	0.89	0.90	0.91	0.91	0.92	0.92	0.92	0.92	0.91	0.91	0.90	0.89	0.89	0.88	0.87	0.86	0.84
ROW = 2:	0.91	0.92	0.93	0.94	0.94	0.94	0.94	0.94	0.94	0.93	0.92	0.92	0.91	0.90	0.88	0.87	0.86
ROW = 3:	0.94	0.95	0.96	0.97	0.97	0.97	0.97	0.97	0.96	0.96	0.95	0.94	0.93	0.91	0.90	0.89	0.88
ROW = 4:	0.96	0.97	0.99	1.00	1.00	1.00	1.00	1.00	0.99	0.98	0.97	0.96	0.95	0.93	0.92	0.91	0.89
ROW = 5:	0.99	1.00	1.02	1.03	1.03	1.04	1.03	1.03	1.02	1.01	1.00	0.99	0.97	0.96	0.94	0.92	0.91
ROW = 6:	1.01	1.04	1.05	1.07	1.07	1.07	1.07	1.06	1.05	1.04	1.03	1.01	0.99	0.98	0.96	0.94	0.92
ROW = 7:	1.04	1.07	1.09	1.11	1.12	1.12	1.11	1.10	1.09	1.07	1.06	1.04	1.02	1.00	0.98	0.96	0.94
ROW = 8:	1.07	1.11	1.14	1.17	1.17	1.16	1.15	1.14	1.12	1.11	1.09	1.06	1.04	1.02	1.00	0.98	0.95
ROW = 9:	1.10	1.14	1.20	1.25	1.23	1.21	1.20	1.18	1.16	1.14	1.12	1.09	1.07	1.04	1.02	0.99	0.97
ROW =10:	1.12	1.17	1.25	1.82	1.29	1.26	1.24	1.22	1.20	1.18	1.15	1.12	1.09	1.06	1.04	1.01	0.98
ROW =11:	1.13	1.18	1.24	1.30	1.30	1.29	1.28	1.27	1.25	1.22	1.18	1.15	1.12	1.09	1.05	1.02	1.00
ROW =12:	1.13	1.18	1.23	1.27	1.29	1.31	1.39	1.33	1.30	1.26	1.22	1.18	1.14	1.10	1.07	1.04	1.01
ROW =13:	1.13	1.17	1.21	1.25	1.29	1.33	1.37	1.64	1.35	1.30	1.25	1.21	1.16	1.12	1.08	1.05	1.02
ROW =14:	1.13	1.17	1.21	1.25	1.29	1.33	1.38	1.41	1.39	1.34	1.29	1.23	1.18	1.14	1.10	1.06	1.02
ROW =15:	1.12	1.17	1.20	1.24	1.29	1.34	1.40	1.45	1.44	1.39	1.32	1.26	1.20	1.15	1.10	1.06	1.03
ROW =16:	1.11	1.15	1.19	1.23	1.28	1.34	1.42	1.69	1.55	1.45	1.35	1.27	1.20	1.15	1.10	1.06	1.03
ROW =17:	1.10	1.13	1.17	1.22	1.27	1.33	1.41	1.53	2,70	1.49	1.35	1.27	1.20	1.15	1.10	1.06	1.02
ROW =18:	1.08	1.12	1.15	1.19	1.24	1.29	1.36	1.44	1.49	1.41	1.32	1.24	1.18	1.13	1.09	1.05	1.02
ROW =19:	1.07	1.10	1.13	1.17	1.20	1.25	1.29	1.33	1.34	1.31	1.26	1.21	1.16	1.12	1.08	1.04	1.01
ROW =20:	1.05	1.07	1.10	1.13	1.17	1.20	1.23	1.25	1.25	1.24	1.20	1.17	1.13	1.09	1.06	1.03	1.00
ROW =21:	1.03	1.05	1.08	1.10	1.13	1.15	1.17	1.18	1.18	1.17	1.15	1.13	1.10	1.07	1.04	1.01	0.98
ROW =22:	1.00	1.03	1.05	1.07	1.09	1.11	1.12	1.13	1.13	1.12	1.11	1.09	1.06	1.04	1.01	0.99	0.96
ROW =23:	0.98	1.00	1.02	1.04	1.06	1.07	1.08	1.09	1.08	1.08	1.07	1.05	1.03	1.01	0.99	0.97	0.95

APPENDIX 4

HERRING STORER ACOUSTICS
Suite 34, 11 Preston Street, Como,
Western Australia, 6152.

Telephone: (09) 367 6200
Facsimile: (09) 474 2579

A.C.N. 009 049 067

ALLAN HERRING M.I.E. AUST. M.A.A.S.
LYNTON STORER M.A.I.E.A., M.A.A.S.

WESTRALIAN SANDS LIMITED

Environmental Noise Modelling
to
Predict Impact of
Conventional Expanded Synthetic Rutile Plant
on
Noise Levels of North Capel.

November 1991 Our ref: 1101-91091

CONTENTS

INTRODUCTION

CONCLUSION

METHOD

RESULTS

ACCEPTABLE LEVELS

DISCUSSION

Data Sheets 1 - 2

Drawing Nos.91091/1 - 4

INTRODUCTION

A study of likely noise emission from the proposed Westralian Sands Synthetic Rutile Plant at Capel, Western Australia has been undertaken in order to assess the impact on the surrounding environs.

This report sets out the methods of determination of noise emission and propagation. The determination of likely acceptable levels and assessment of impact due to operational noise of the proposed plant. The proposed plant although autonomous is an expansion of existing facilities at Westralian Sands, North Capel operations.

CONCLUSION

It is the conclusion of this report that acceptable levels of noise emission to the nearest resident's surrounding the proposed plant will be 40 to 45 dBA providing no tonal or other annoying characteristics exist.

The proposed plant will generate noise emission that, when propagated to the surrounding area, will be less than existing noise levels by approximately 10 dBA.

Under certain conditions, the generated noise may marginally exceed the 45 dBA criteria to a residential property near the intersection of Cable Mine Road and Bussell Highway but is considered not to be such that complaints would arise.

METHOD

To help assess the existing acoustic environment and determine the existing plant sound level emission sound level monitoring was undertaken. Sound level data was recorded at a number of locations around the plant along with wind and temperature. This data was recorded in 1/3 Octave Bands and by reverse propagation calculations, using the ENM (Environmental Noise Model) computer programme, the existing plant sound power level was calculated.

File data of a modern S.R. plant was used to similarly calculate the sound power level of the proposed plant.

The ENM programme was used to determine noise propagation based on input of the above sound powers, surrounding topography and atmospheric conditions. The results being output in the form of noise level contours. Sound level contours were generated for the existing plant, new plant and both plants. Also predictions were made for the new plant under adverse wind conditions.

RESULTS

The results of noise level measurements of the existing plant are summarized on Data Sheet 91091D/1 in Appendix A along with the calculated sound power levels.

The existing plant sound power levels were modelled as four point sources being 2 for the S.R. Plant, 1 for the Dry Plant and 1 for the Water Treatment Plant.

The results of the determined sound power levels for the proposed plant are shown on Data Sheet 91091D/2. The proposed plant was modelled as 5 point sources, 4 being around the plant and the other being the Lime Plant.

The results of the computer modelling in the form of noise level contours are shown on Drawing No.91091/1 to 4 in Appendix B.

ACCEPTABLE LEVELS

The nearest residences are to the north east of the plant, relatively close to the intersection of Yeardy Road & Bussell Highway and also along Cable Mine Road.

In terms of the Environmental Protection Act 1986 Regulations, the areas around Bussell Highway range from category B1 to B2 for determination of the Assigned Outdoor Neighbourhood Noise Level. For the worst case situation of the period 2200 to 0700 hours, the level would be 40 to 45 dBA. Residences along Cable Mine Road are likely to be classified under Category A1 or A2 being 30 to 35 dBA.

The current policy of the Environmental Protection Authority is to standardise on levels of 40 dBA (for the worst case time period of 2200 hrs to 0700 hours).

The existing noise levels are in the range 40 to 45 dBA being higher towards Bussell Highway due to traffic.

It is considered as an overall policy noise levels of 40 to 45 dBA are likely to be acceptable providing no annoying characteristics exist such as tonal components.

DISCUSSION

Prediction of existing plant noise levels are shown on Drawing No.91091/1 and Figure 1 indicating levels of 40 to 42 dBA at the nearest residential locations discussed. This is supported by survey levels conducted by Westralian Sands Ltd and by measurements taken during the course of this study.

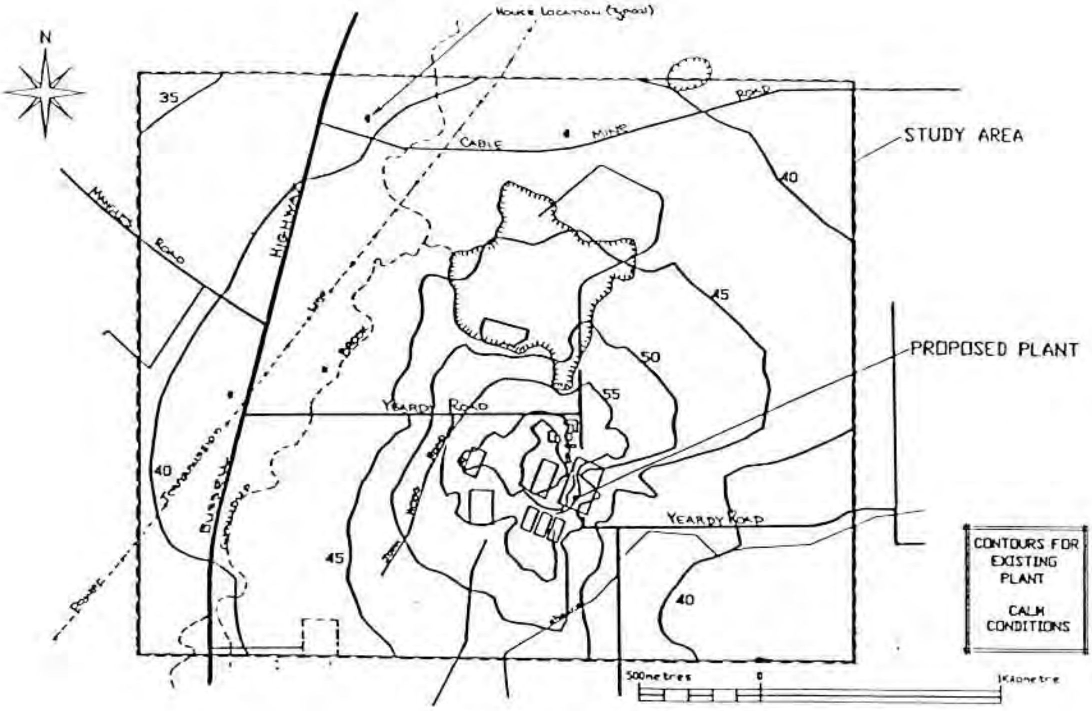


Figure 1

Predictions of noise levels due to the proposed plant are shown on Drawing No.91091/2 and Figure 2. This prediction is for calm conditions and indicate levels of 30 to 35 dBA at the stated locations. A 10 dBA differential between existing and proposed plants means there will be no additive effect and hence resultant levels of the combined plant will be 40 to 43 dBA as shown on the Drawing No.91091/3 and Figure 3.

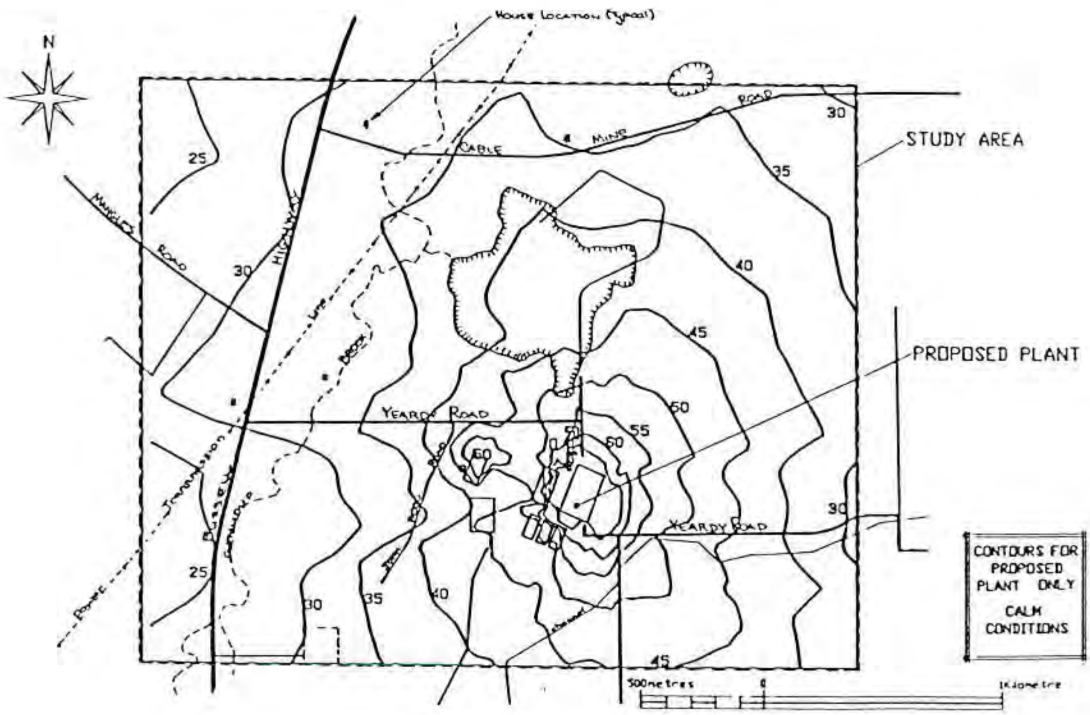


Figure 2

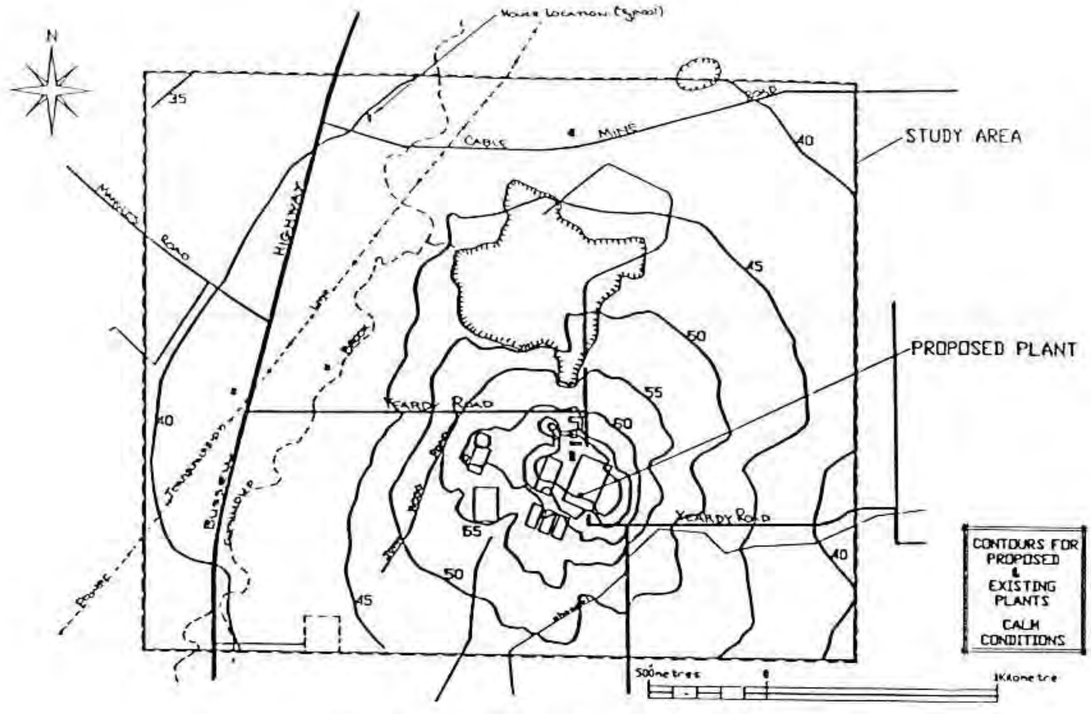


Figure 3

The considered worst case scenario for the new plant is with S.E. breeze at 3m/sec and results of modelling of this case is shown on Drawing No.91091/4 and Figure 4 with predicted levels of generally less than 45 dBA except for a pocket near the intersection of Cable Mine Road and Bussell Highway where levels up to 46 dBA could be experienced. providing no tonal components or other annoying characteristics exist in the noise, these levels are unlikely to cause adverse reaction in part due to limited occurrence and also due to the fact that ambient noise levels increase with such wind speeds.

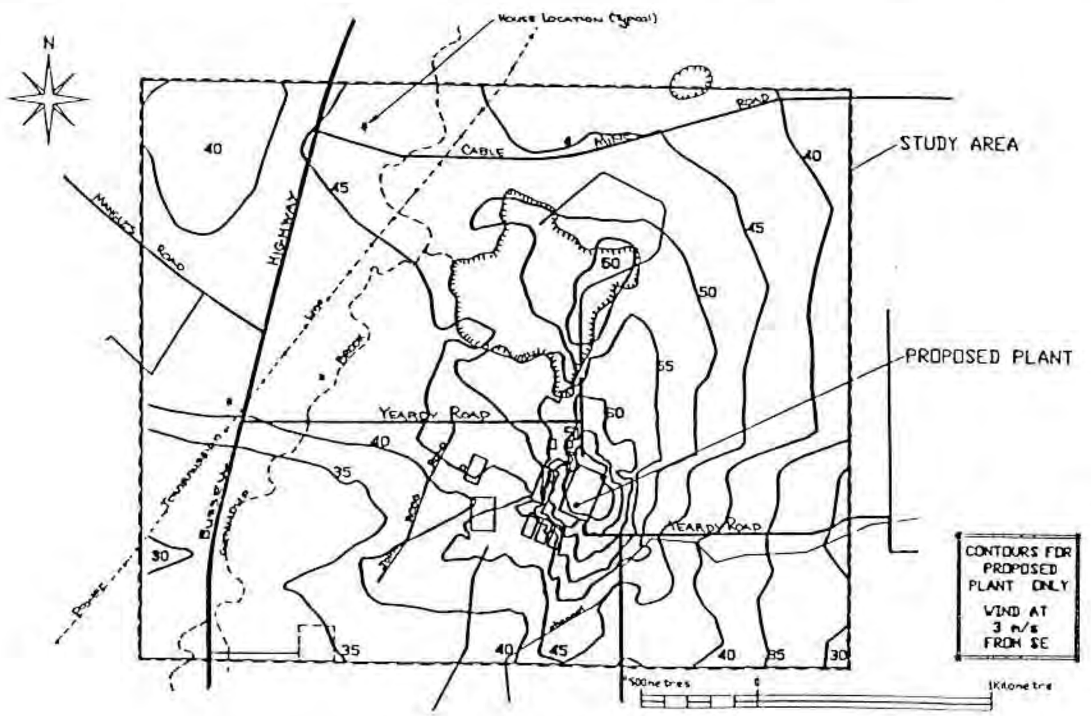


Figure 4

To achieve the predicted levels, sound attenuation of some plant is required, this particularly applies to supply and induced draft, dryer, scrubber, ventilation and dust collection fans. Generally this requires inlet and or discharge silencers and acoustic lagging to fan cases and parts of ducting.

As an overall rule, equipment should achieve a noise level rating of 85 dBA at 3m under free field conditions. If tonal components exist the required level should be reduced by 5 dBA or the tonal component reduced to a level equivalent to the surrounding octave band levels.

For HERRING STORER ACOUSTICS

Lynton Storer, M.A.I.E.A., M.A.A.S.

Worksheet #:1	Title:WESTRALIAN SANDS	DATA SHEET 91091D/1

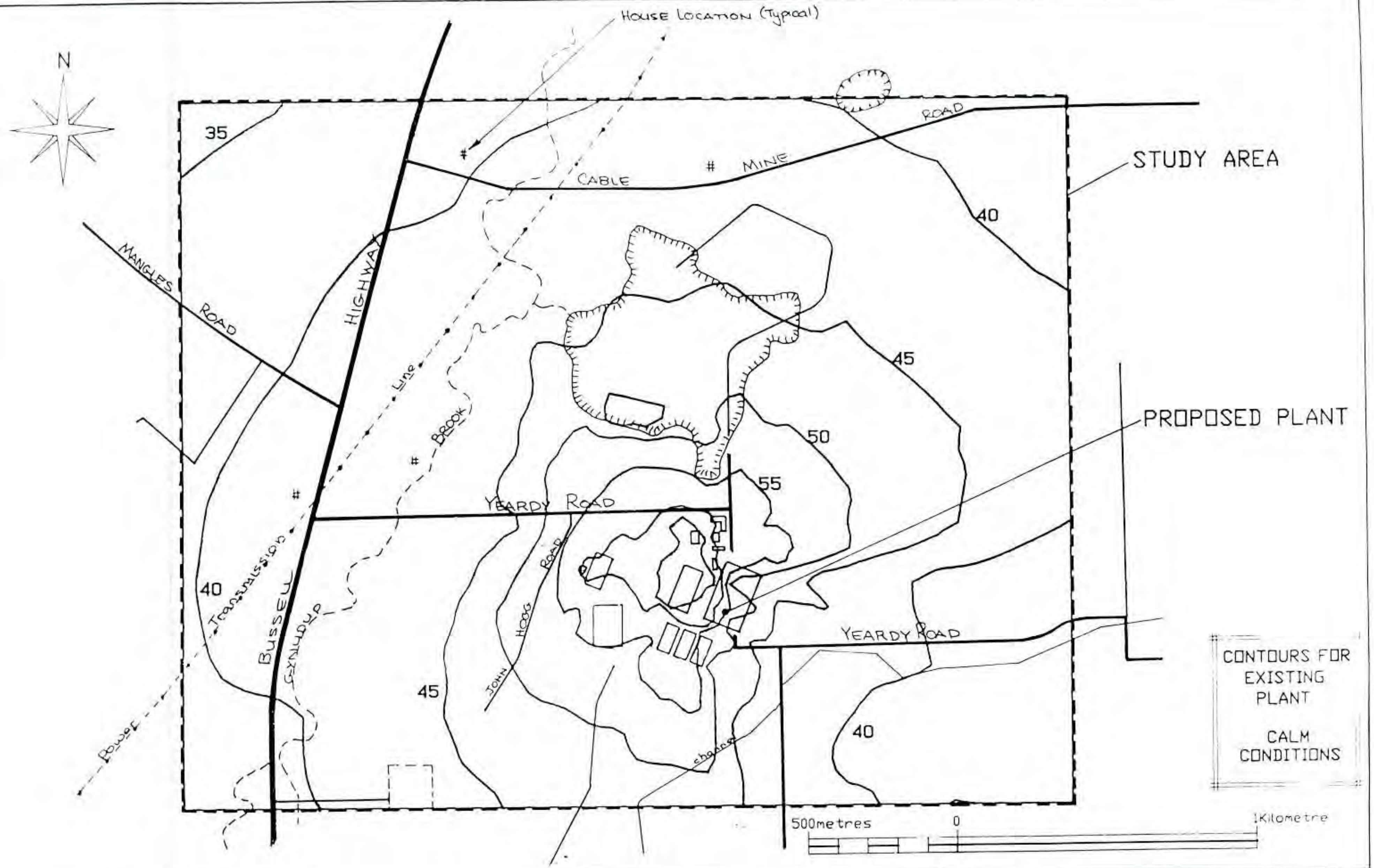
MEASUREMENTS OF EXISTING PLANT 27/9/91

Octave Hz	31.5	63	125	250	500	1k	2k	4k	8k	16k	Lin/Awt
LOCATION A											
SPECT. 1	62.0	54.0	44.0	48.0	43.0	35.0	27.0	24.0	21.0	17.0	62.9 43.8
LOCATION B											
SPECT. 2	66.0	60.0	53.0	45.0	45.0	42.0	37.0	30.0	26.0	15.0	67.2 47.1
LOCATION C											
SPECT. 3	73.0	67.0	66.0	61.0	58.0	56.0	51.0	45.0	34.0	17.0	75.0 60.8
LOCATION D											
SPECT. 4	75.0	69.0	70.0	59.0	57.0	58.0	51.0	43.0	28.0	16.0	77.1 61.6
LOCATION E											
SPECT. 5	78.0	72.0	73.0	61.0	61.0	58.0	53.0	44.0	34.0	22.0	80.1 63.5
LOCATION F											
SPECT. 6	72.0	63.0	57.0	47.0	51.0	51.0	45.0	37.0	24.0	15.0	72.7 54.2
SWL DETERMINED FROM LOCATION D (SOURCE 1)											
SPECT. 7	129.3	126.4	136.0	120.1	117.3	116.4	113.2	112.0	112.0	116.0	137.5 124.0
SWL DETERMINED FROM LOCATION B (SOURCE 2)											
SPECT. 8	128.9	123.1	117.7	118.7	115.0	115.1	115.6	117.8	126.0	115.0	132.3 127.0
SWL DETERMINED FROM LOCATION E (SOURCE 3)											
SPECT. 9	119.5	114.5	123.1	110.3	106.0	104.4	100.0	92.9	87.4	89.2	125.3 111.1
SWL DETERMINED FROM SOURCE F (SOURCE 4)											
SPECT. 10	100.0	104.0	99.0	90.0	89.0	91.0	89.0	83.0	70.0	62.0	106.7 95.2

Worksheet #:2	Title:WESTRALIAN SANDS	DATA SHEET 91091D/2

MEASURED DATA OF TYPICAL MODERN SR PLANT

1/3 Oct Hz	31.5	63	125	250	500	1k	2k	4k	8k	16k	Lin/Awt
100m FROM KILN SIDE											
SPECT. 1	66.0	68.0	68.0	63.0	55.0	50.0	46.0	40.0	29.0	25.0	77.5
	68.0	70.0	62.0	59.0	51.0	48.0	44.0	36.0	25.0	25.0	
	66.0	70.0	61.0	58.0	53.0	46.0	42.0	34.0	62.0	25.0	63.4
20m DUST COLLECTOR END (PLAN NORTH)											
SPECT. 2	71.0	75.0	71.0	73.0	67.0	60.0	53.0	50.0	41.0	25.0	84.0
	72.0	75.0	71.0	70.0	62.0	58.0	53.0	48.0	36.0	25.0	
	75.0	73.0	74.0	71.0	64.0	56.0	52.0	45.0	65.0	25.0	72.1
75m AERATOR BLOWER HOUSE SIDE											
SPECT. 3	75.0	76.0	73.0	73.0	71.0	64.0	61.0	59.0	51.0	37.0	87.1
	71.0	78.0	74.0	69.0	66.0	63.0	59.0	56.0	49.0	35.0	
	73.0	81.0	80.0	71.0	66.0	63.0	59.0	54.0	45.0	35.0	75.1
PLAN SOUTH END											
SPECT. 4	74.0	71.0	74.0	71.0	59.0	57.0	51.0	47.0	39.0	27.0	84.4
	77.0	74.0	73.0	63.0	58.0	53.0	50.0	44.0	35.0	25.0	
	75.0	77.0	72.0	62.0	59.0	52.0	49.0	42.0	65.0	25.0	68.9
CALCULATED SWL SOURCE 4 (FROM S1)											
SPECT. 5	115.0	117.0	117.0	112.0	104.0	99.0	95.0	89.0	78.0	74.0	126.5
	117.0	119.0	111.0	108.0	100.0	97.0	93.0	85.0	74.0	74.0	
	115.0	119.0	110.0	107.0	102.0	95.0	91.0	83.0	111.0	74.0	112.4
CALCULATED SWL SOURCE 5 (FROM S2)											
SPECT. 6	123.0	120.0	123.0	120.0	108.0	106.0	100.0	96.0	88.0	76.0	133.4
	126.0	123.0	122.0	112.0	107.0	102.0	99.0	93.0	84.0	74.0	
	124.0	126.0	121.0	111.0	108.0	101.0	98.0	91.0	114.0	74.0	117.9
CALCULATED SWL SOURCE 6 (FROM S3)											
SPECT. 7	118.0	119.0	116.0	116.0	114.0	107.0	104.0	102.0	94.0	80.0	130.1
	114.0	121.0	117.0	112.0	109.0	106.0	102.0	99.0	92.0	78.0	
	116.0	124.0	123.0	114.0	109.0	106.0	102.0	97.0	88.0	78.0	118.1
CALCULATED SWL SOURCE 7 (FROM S4)											
SPECT. 8	106.0	110.0	106.0	108.0	102.0	95.0	88.0	85.0	76.0	60.0	119.0
	107.0	110.0	106.0	105.0	97.0	93.0	88.0	83.0	71.0	60.0	
	110.0	108.0	109.0	106.0	99.0	91.0	87.0	80.0	100.0	60.0	107.1
CALCULATED SWL SOURCE 8 (LIME PLANT)											
SPECT. 9	101.0	97.0	100.0	103.0	104.0	103.0	101.0	96.0	86.0	70.0	110.4
											107.6



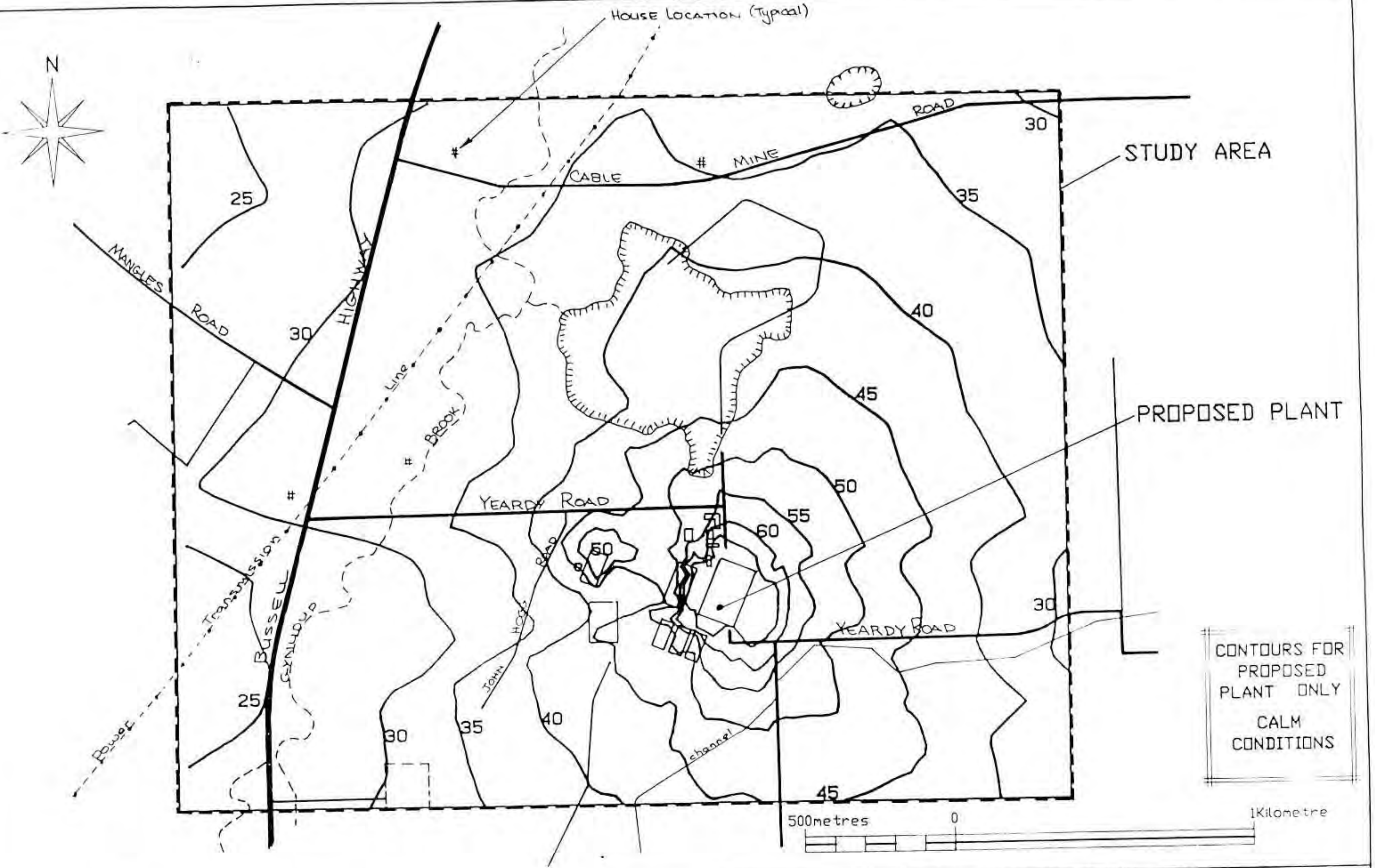
ALL NOISE LEVELS SHOWN ARE EQUIVALENT TO SHORT TERM Leq (dBA)

CONTOURS ARE IN 5dBA STEPS

DATE: OCT. 1991	SCALE: AS SHOWN	BY: L. STORER	DRG. NO. 91091/1

WESTRALIAN SANDS LIMITED
PROPOSED NORTH CAPEL SR PLANT
NOISE LEVEL PREDICTIONS

HERRING STORER ACOUSTICS
Suite 34, 11 Preston Street Como
Western Australia, 6152
Telephone: (09)3676200
Facsimile: (09)4742579



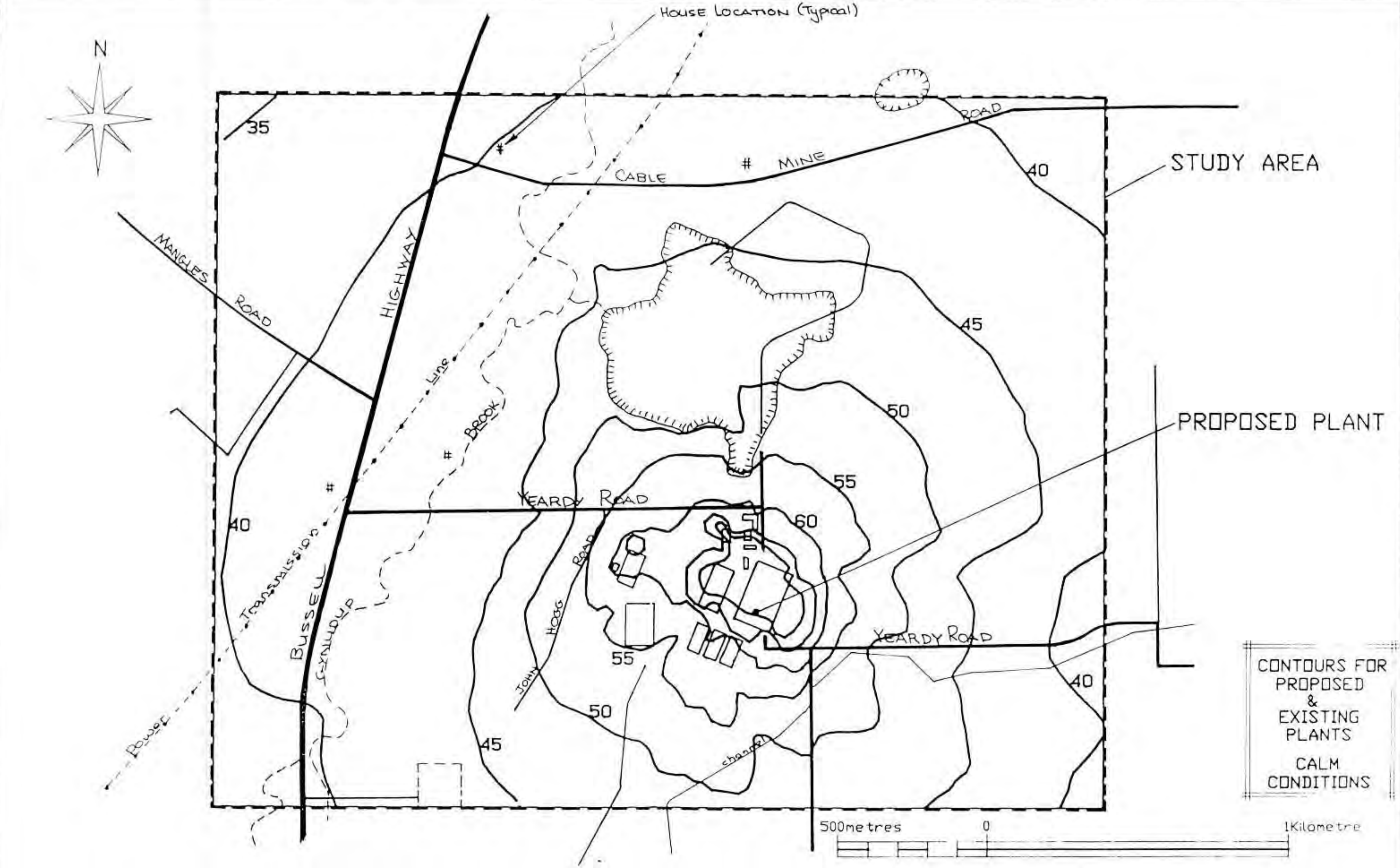
ALL NOISE LEVELS SHOWN ARE EQUIVALENT TO SHORT TERM Leq (dBA)

CONTOURS ARE IN 5dBA STEPS

DATE: OCT. 1991	SCALE: AS SHOWN	BY: L. STORER	DRG. NO. 91091/2

WESTRALIAN SANDS LIMITED
PROPOSED NORTH CAPEL SR PLANT
NOISE LEVEL PREDICTIONS

HERRING STORER ACOUSTICS
Suite 34, 11 Preston Street Como
Western Australia, 6152
Telephone: (09)3676200
Facsimile: (09)4742579



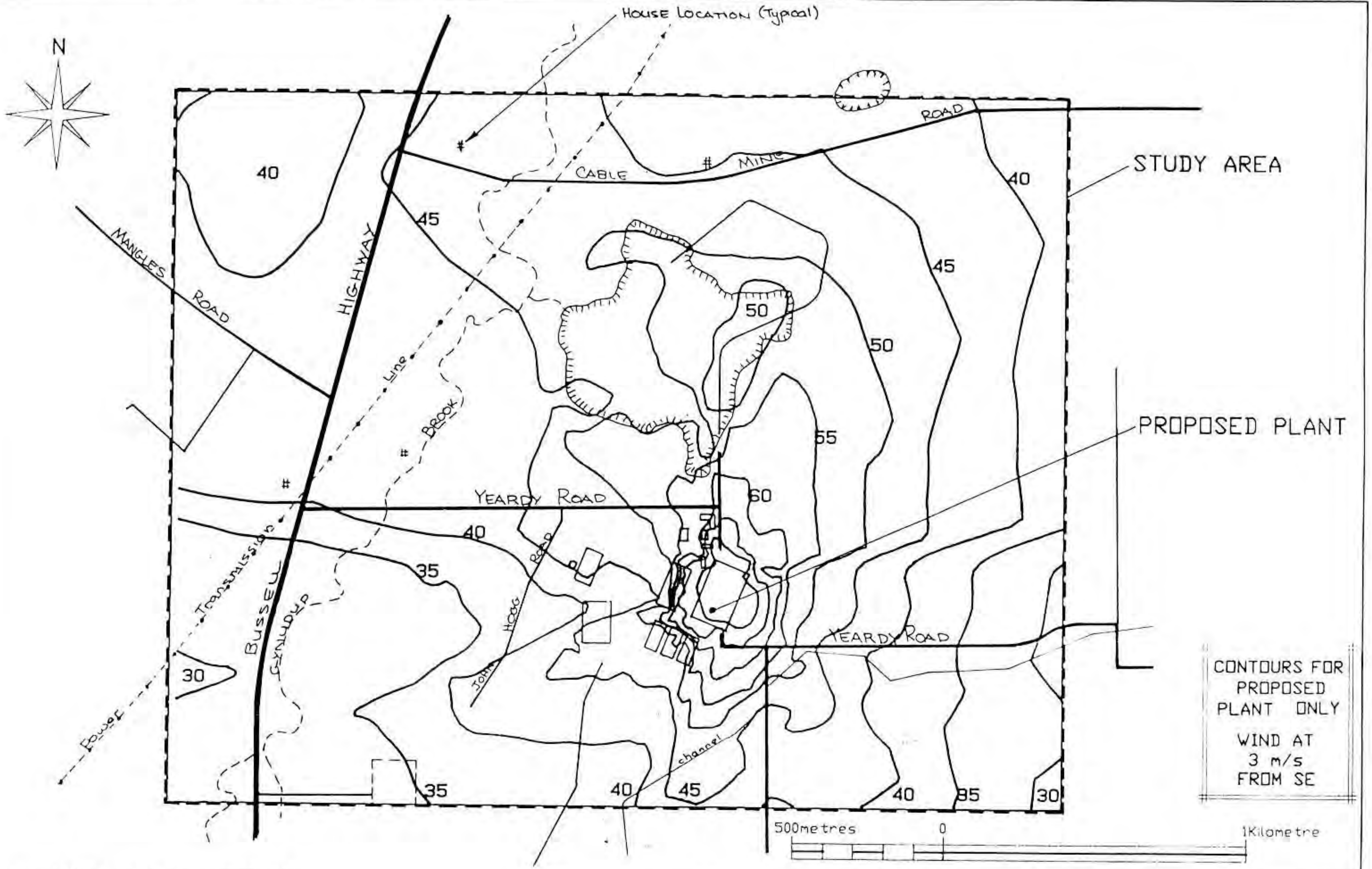
ALL NOISE LEVELS SHOWN ARE EQUIVALENT TO SHORT TERM Leq (dBA)

CONTOURS ARE IN 5dBA STEPS

DATE: OCT. 1991	SCALE: AS SHOWN	BY: L. STORER	DRG. NO. 91091/3

WESTRALIAN SANDS LIMITED
PROPOSED NORTH CAPEL SR PLANT
NOISE LEVEL PREDICTIONS

HERRING, STORER ACOUSTICS
Suite 34, 11 Preston Street Como
Western Australia, 6152
Telephone: (09)3676200
Facsimile: (09)4742579



ALL NOISE LEVELS SHOWN ARE EQUIVALENT TO SHORT TERM Leq (dBA)

CONTOURS ARE IN 5dBA STEPS

DATE: OCT. 1991	SCALE: AS SHOWN	BY: L. STORER	DRG. NO 91091/4

WESTRALIAN SANDS LIMITED
PROPOSED NORTH CAPEL SR PLANT
NOISE LEVEL PREDICTIONS

HERRING STORER ACOUSTICS
Suite 34, 11 Preston Street Como
Western Australia, 6152
Telephone: (09)3676200
Facsimile: (09)4742579

APPENDIX 5

HERRING STORER ACOUSTICS
Suite 34, 11 Preston Street, Como,
Western Australia, 6152.
Telephone: (09) 367 6200
Facsimile: (09) 474 2579
A.C.N. 009 049 067

ALLAN HERRING M.I.E. AUST. M.A.A.S.
LYNTON STORER M.A.I.E.A. M.A.A.S.

WESTRALIAN SANDS LIMITED

Environmental Noise Modelling to Predict Frequency of Emissions and Impact of Conventional Expanded Synthetic Rutile Plant on Noise Levels of North Capel.

07 July 1992

Our ref: 0213-91091

FREQUENCY OF EMISSIONS

FORWARD

This report is concerned with the examination of the frequency of noise emissions from the North Capel Complex due to various wind conditions.

The study area has been expanded compared to the original study to encompass all of the nearest residences within 360° of the plant. The various residential locations numbered 1 to 15 are shown on the Drawing 91091/05.

The same mathematical computer model (ENM) was used to predict noise levels to individual locations as was used in the overall study.

Predictions were made for various wind strength with wind direction being directly from the plant to the specific place of receipt of noise. Percentages of occurrence were based on wind of various speeds being present anywhere within a 67.5° quadrant of the plant. That is, for a location due north of the plant the maximum propagation is considered to occur when wind direction is anywhere from south south east to south south West. The percentage of these occurrences is taken from Wind Roses of Glen Iris Meteorological Data, specifically the 1982/83 period.

The results of these calculations are shown on Table 1, figure 1 for the plant expansion emission only. For comparison, a table of existing noise levels are shown in Table 2 for the same wind speeds.

DISCUSSION

Data has been broken down into wind speeds of 0 to 0.5 m/s (calm). 0.5 to 3 m/s and 3 to 4.5 m/s. Maximum propagation is considered to occur in the 0.5 to 3m/s range as at greater speed, propagation is increased, however, background noise levels are also increased due to wind noise in trees, on buildings etc. which renders noise less intrusive .

In considering the frequency of occurrence, it must be pointed out that the values shown are conservative in that all occurrences of the various wind speeds have been considered but no allowance is made for other conditions (such as rain) that can occur during these wind conditions that can considerably increase background levels and hence mask any intrusive noise. Also noise levels are computed at the maximum wind speed in a given range, for instance in the range 0.5 to 3.0m/s levels are computed for 3m/s.

TABLE 02

WESTRALIAN SANDS NORTH CAPEL: EXPANSION PLANT

SOUND PRESSURE LEVELS AT VARIOUS WIND SPEEDS & PERCENTAGE OCCURRENCE FOR WIND WITHIN A 62.5° QUADRANT OF THE RECEIVER LOCATION

LOCATION	WIND SPEED					
	0 TO 0.5 m/s		0.5 TO 3.0 m/s		3.0 TO 4.5 m/s	
	SPL (dBA)	% OCCURRENCE	SPL (dBA)	% OCCURRENCE	SPL (dBA)	% OCCURRENCE
1	35	0.2	35 - 50	8.3	50 - 54	5.3
2	33	"	33 - 44	11.4	44 - 49	8.4
3	28	"	28 - 43	11.4	43 - 46	8.4
4	25	"	25 - 38	11.4	38 - 42	8.4
5	27	"	27 - 40	11.3	40 - 44	7.8
6	33	"	33 - 45	11.3	45 - 49	8.0
7	21	"	21 - 35	6.9	35 - 39	4.0
8	36	"	36 - 45	4.7	45 - 48	3.2
9	24	"	24 - 41	4.7	41 - 44	3.2
10	25	"	25 - 39	3.0	39 - 43	3.8
11	20	"	20 - 32	3.1	32 - 38	4.6
12	20	"	20 - 32	4.0	32 - 35	5.3
13	18	"	18 - 31	9.7	31 - 34	6.0
14	22	"	22 - 37	11.3	37 - 41	8.0
15	19	"	19 - 28	11.3	28 - 31	7.8

FIGURE 01

TABLE 01

WESTRALIAN SANDS - NORTH CAPEL: COMBINED PLANTS

SOUND PRESSURE LEVELS AT VARIOUS WIND SPEEDS & PERCENTAGE OCCURRENCE FOR WIND WITHIN A 62.5° QUADRANT OF THE RECEIVER LOCATION

LOCATION	WIND SPEED					
	0 TO 0.5 m/s		0.5 TO 3.0 m/s		3.0 TO 4.5 m/s	
	SPL (dBA)	% OCCURRENCE	SPL (dBA)	% OCCURRENCE	SPL (dBA)	% OCCURRENCE
1	42	0.2	42 - 55	8.3	55 - 58	5.3
2	40	"	40 - 53	11.4	53 - 56	8.4
3	35	"	35 - 49	11.4	49 - 52	8.4
4	34	"	34 - 45	11.4	45 - 48	8.4
5	34	"	34 - 47	11.3	47 - 50	7.8
6	41	"	41 - 54	11.3	54 - 58	8.0
7	33	"	33 - 46	6.9	46 - 49	4.0
8	39	"	39 - 51	4.7	51 - 54	3.2
9	33	"	33 - 47	4.7	47 - 51	3.2
10	31	"	31 - 46	3.0	46 - 49	3.8
11	29	"	29 - 45	3.1	45 - 48	4.6
12	30	"	30 - 42	4.0	42 - 46	5.3
13	33	"	33 - 44	9.7	44 - 47	6.0
14	32	"	32 - 45	11.3	45 - 45	8.0
15	29	"	29 - 42	11.3	42 - 45	7.8

FIGURE 2

RESULTS

The expansion plant produces noise levels that generally will not increased the existing noise levels under maximum propagation conditions, the exception being location 1 directly to the north of the plant where levels are predicted to increase by 2 dB(A). Excursions of over 40 dB(A) with respect to night time criteria can occur up to a maximum of 19% of the time at any one location. Excursions of the 50 dB(A) day time criteria do not occur (up to 3m/s wind speed).

DISCUSSION OF RESULTS & RECOMMENDATIONS

Mathematical modelling predicts, for maximum propagation condiotns, and night time that the expansion plant can exceed the Environmental Protection Authority criteria of 40 dB(A) by up to 5 dB(A) for a maximum of 17% of the time at 6 locations. These oise levels however, will have negligible effect in terms of an increase of the existing levels except at location 1 (by 2 dB(A)).

The modelling is based on a plant that is similar to the proposed expansion plant and not necessarily the same. Knowing the major noise sources of the modelled plant then the opportunity exists to engineer lower noise levels into the design of the proposed expansion plant. These engineering solutions are technically feasible and considered practicable to implement. The solutions primarily will take the form of fan discharge and or inlet silencers and acoustic lagging. It is within the scope of this study to predict available reductions of up to 5 dB(A) from the proposed expansion plant and would ensure that levels for worst case conditions do not exceed the E.P.A. criteria, the exception being Location 1 on Cable Mine Road.

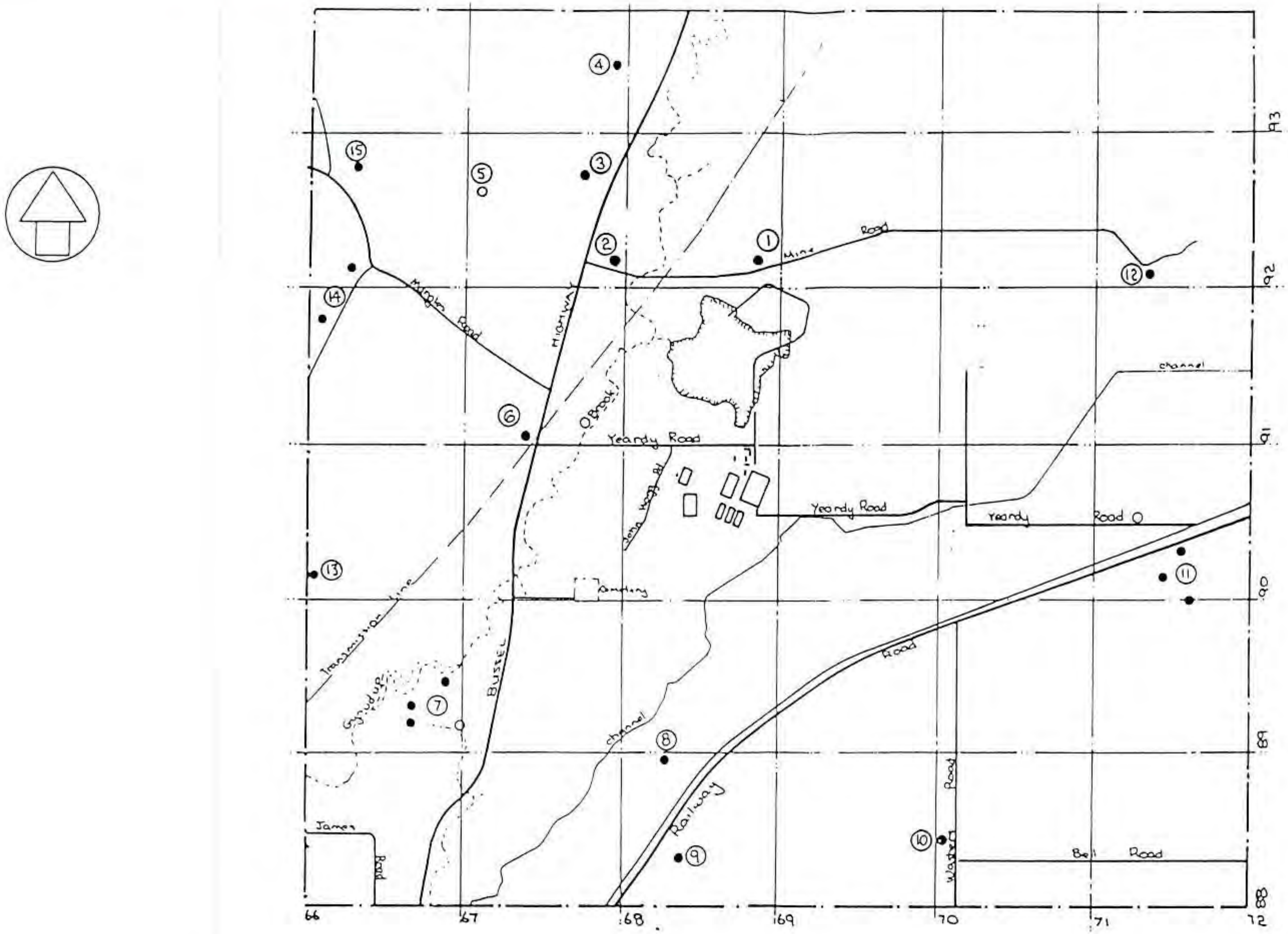
It can be seen from the noise contours in the previous report that noise levels are greatly influenced by the bund at the northern end of the sand pit that is to the south of Location 1. Reductions in noise levels of 5 dB(A) could be realised by extending this bund to the east which would bring location 1 to within the EPA criteria.

It is recommended that, in the design of the expansion plant, specifications ensure that suppliers of equipment are required to meet noise level criteria, that would be specified and would be frequency dependant, that would have an overall criteria of 85 dB(A) at 3 metres distance under free field conditions.

It is also recommended that investigations be undertaken in parallel with plant design, to extend the sand pit northern end bund to the west.

Yours faithfully
for HERRING STORER ACOUSTICS

Lynton Storer



DATE: JUNE 1992	SCALE: 1 25000	WESTRALIAN SANDS LIMITED	HERRING STORER ACOUSTICS
BY: L. STORER	DRG. NO 91091/05	EXPANDED NORTH CAPEL SR PLANT NOISE LEVEL PREDICTIONS - RESIDENTIAL LOCATIONS	Suite 34, 11 Preston Street Como Western Australia 6152 Telephone: (09)3676200 Facsimile: (09)4742579

APPENDIX 6

AIR DISPERSION MODELLING STUDY OF WESTRALIAN SANDS NORTH CAPEL SYNTHETIC RUTILE PLANT

for

Westralian Sands Limited

DAMES & MOORE

Dames & Moore Job No. 14365-022-071

June 1992

DAMES & MOORE

SOUTHSHORE CENTRE, 85 THE ESPLANADE, [illegible]
TELEPHONE (09) 367 8255 FACSIMILE (09) [illegible]

18 June 1992

Westralian Sands Limited
PO Box 96
CAPEL WA 6271

Attention: Mr Ron Palmer

Dear Sir,

AIR DISPERSION MODELLING STUDY OF
WESTRALIAN SANDS NORTH CAPEL
SYNTHETIC RUTILE PLANT

Please find enclosed our final report entitled "Air Dispersion Modelling of Westralian Sands North Capel Synthetic Rutile Plant". This report presents the results of three separate studies conducted as part of the air dispersion modelling exercise. These separate studies were:

- AUSPLUME air dispersion modelling conducted by Dames & Moore;
- worst-case air dispersion modelling of convective and fumigation conditions by CSIRO; and
- an investigation of meteorological factors affecting plume dispersion conducted by Bureau of Meteorology.

The AUSPLUME air dispersion modelling results indicated that under normal atmospheric conditions the sulphur dioxide emissions from WSL would not exceed any of the proposed standards or limits. The air dispersion modelling exercise conducted by CSIRO found that high groundlevel concentrations of sulphur dioxide could be expected to occur under fumigation and convective conditions. Groundlevel concentrations of sulphur dioxide are predicted to approach the residential limit of 700µg/m^3 at approximately 1,000m from the source under convective conditions with a limited mixing depth, following early morning fumigation. The data analysis conducted by the Bureau of Meteorology found that, on average, there are about seven events per year where these worst case conditions occur.

Please do not hesitate to contact Brian Bell or myself should you have any comments or further questions.

Yours faithfully
DAMES & MOORE

B G Muir
Consultant-in-Charge
Environmental Services

BB:/14365-022-071/144-3538

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AIR DISPERSION MODELLING STUDY OF WESTRALIAN SANDS NORTH CAPEL SYNTHETIC RUTILE PLANT

1.0 INTRODUCTION

Westralian Sands Limited (WSL) is currently investigating the possibility of building a second Synthetic Rutile (SR) plant next to its existing SR plant at North Capel. One of the issues that has to be investigated is the groundlevel concentrations of sulphur dioxide that are likely to result from the final sulphur dioxide emissions scenario. Dames & Moore has been requested by WSL to undertake this air dispersion modelling work. The air dispersion modelling study was conducted in three parts:

- o AUSPLUME air dispersion modelling conducted by Dames & Moore;
- o worst-case air dispersion modelling of convective and fumigation conditions by CSIRO; and
- o an investigation of meteorological factors affecting plume dispersion conducted by Bureau of Meteorology.

This report presents the findings of the air dispersion modelling study.

2.0 RELEVANT INFORMATION

2.1 EMISSIONS INFORMATION

WSL has supplied the expected emissions characteristics for the final scenario and these are presented in Table 1. The emissions from the proposed SR-2 kiln and drier, as well as the existing SR-1 kiln, would be ducted to a central stack. The existing SR-1 drier and the Dry Plant emissions would continue to be emitted from their stacks. Table 1 presents the emissions characteristics of Associated Minerals Consolidated (AMC), as supplied by the Environmental Protection Authority (EPA). The EPA directed WSL to consider the AMC emission sources in the modelling exercise.

TABLE 1

EMISSIONS CHARACTERISTICS

	Volume at Stack Conditions (m^3/s)	*Emission Temperature (°C)*	*Sulphur Dioxide Emission Rate (g/s)*	*Stack Height (m)*	*Stack Diameter (m)*
SR-1 & 2 Kiln, SR-2 Drier	72.2	110	215.0	110.0	2.5
SR-1 Drier	6.3	60	15.0	35.5	1.0
North Capel Drier	7.8	60	2.5	4.5	1.5
AMC Source 1	3.0	70	0.5	45.0	0.6
AMC Source 2	7.0	70	1.3	90.0	1.0

2.2 METEOROLOGICAL DATA

The State Energy Commission of WA collected meteorological information at Glen Iris, east of Bunbury, from April 1982 to July 1983. As part of the 1985 Kemerton Aluminium Smelter study, the EPA (formally the Department of Conservation and Environment) (Pitt *et al.*, 1985) analysed 12 months of this data set collected at Glen Iris between 14 July 1982 and 13 July 1983. After careful consideration of the available meteorological data, EPA concluded that in the absence of more detailed site specific meteorological data, the data from the Glen Iris site should be used for any air dispersion modelling. The reasons were:

- o "When compared to any other site in the region, the far greater number of measured variables describing meteorological conditions would enable more confidence to be placed on dispersion estimates."

- o "The accuracy of the Glen Iris data was far greater than corresponding data measured at any other location. The sensors were superior in precision and all processing was performed by computer. Alternative data which were interpreted and digitised from charts were subject to far greater inaccuracies."

o "Since the main meteorological sensors at Glen Iris were mounted 27m above groundlevel, the data more closely measured atmospheric parameters affecting plume dispersion ... than data collected 10m above groundlevel as was the case at all other sites. Also, data collected at the greater height were considered free from topographical influences, which may have exerted localised biases on data collected at the lower height."

In addition, the Glen Iris and WSL sites are similar distances inland. Pitt *et al.* (1985) stated that "based on previous experience gained during the Kwinana Air Modelling Study (Paparo, 1982), differences in near-coastal meteorology within a given coastal region are primarily a function of distance inland from the coast and not latitudinal variation."

The use of a limited data set (i.e. 1 year) for modelling purposes is generally acceptable providing the modelled year is representative of the longer-term trends. Pitt *et al.*, (1985) compared the one year wind rose to the four year average wind rose and concluded that the single year of data used for modelling was representative of longer-term average data.

As part of their study on the proposed Aluminium Smelter, Pitt *et al.* (1985) created a data set that was suitable as input to a number of air dispersion models. During onshore wind conditions, the effects of the sea-breeze were included by calculating the height of the Thermal Internal Boundary Layer (TIBL) at the site being considered (Kemerton). This height was included in the data file and, therefore, the data set implicitly includes the effects of limited mixing under onshore wind conditions. This is an important feature of a coastal environment such as Kemerton. Since this study, Dames & Moore (1990) has used the same meteorological data to produce a data file suitable for use by AUSPLUME. This data set has been used in the current study, with the exception that the onshore mixing height has been modified to reflect the TIBL at the WSL site. The methodologies employed by the EPA to generate the Kemerton mixing heights were used for the WSL site. The TIBL height has been determined under onshore winds and this has been incorporated into the meteorological data file.

The seasonal and annual wind roses are presented in Figure 1. The summer wind pattern is dominated by the diurnal land-breeze/sea-breeze pattern of light night-time and morning south-easterlies followed by stronger afternoon westerly sea-breezes. In autumn, the occurrence of sea-breezes decreases and the easterly to south-easterly winds are dominant. In the winter, the wind pattern is more directly related to the synoptic flow. Relatively strong winds from the north-west are more frequent and offshore winds are more diverse in their direction of origin. The spring wind pattern shows that south-easterly to southerly winds are more common and afternoon sea-breezes start to affect the wind pattern. The annual wind rose reflects the seasonal trends, with easterly to southerly winds generally being predominant. The presence of afternoon sea-breezes are reflected in the occurrence of west-south-westerly to westerly winds.

In addition to the Glen Iris data, WSL have been collecting site-specific data for a period of time. Unfortunately, at the time of this study the overall data recovery from this station was low, and there were many substantial data gaps. It is difficult, therefore, to readily compare trends in the data recorded at Glen Iris and WSL. As such, the Glen Iris data has been used in this study.

2.3 AIR DISPERSION MODELS

2.3.1 AUSPLUME Air Dispersion Model

The Victorian Environment Protection Authority (VEPA) regulatory Gaussian plume dispersion model, AUSPLUME, has been used to model the cumulative impact of all of the sulphur dioxide emissions sources. AUSPLUME was developed from the United States Environmental Protection Agency (US EPA) ISCST model. It generally utilises the best methods available in the international literature. The AUSPLUME model is widely used throughout Australia by Regulatory Authorities and air modelling consultants and as a result of this, is well documented (see VEPA, 1986). AUSPLUME is designed to predict groundlevel concentrations or dry deposition of pollutants emitted from one or more sources. It is often used for:

- stack height determination;
- new source assessment;
- the effects of buildings on plume dispersion;
- monitoring network design;
- identification of the main contributors to existing air pollution problems; and
- control strategy evaluation;

AUSPLUME can be used to model single or multiple point, volume or area sources. As such each pollutant source is modelled individually to determine the total impact of the whole plant. The total plant impact is the arithmetic total of the groundlevel concentration from each source at each receptor (grid) point at each model time step.

The meteorological data used by AUSPLUME comprises time series data directly related to the area being studied. This data set contains 1-hourly averages of wind speed, wind direction, air temperature, atmospheric stability class, atmospheric mixing depth and sigma theta.

The AUSPLUME model has been modified, by Dames & Moore, to record:

- the number of hours at each grid point where a nominated 1-hour average groundlevel concentration was exceeded;
- the number of days at each grid point where the nominated 1-hour average groundlevel concentration was exceeded;
- the meteorological conditions under which the nominated 1-hour average concentration was exceeded anywhere over the modelled grid; and
- the ten highest 1-hour average groundlevel concentrations for each model grid point.

2.3.2 CSIRO Lagrangian Atmospheric Dispersion Model

The AUSPLUME air dispersion model does not treat morning fumigation or convective conditions. In recent years CSIRO have developed the Lagrangian Atmospheric Dispersion Model (LADM) which can be utilised to predict groundlevel concentrations of pollutants under these conditions. LADM has three modules:

The wind field module. The winds in the growing morning boundary layer are computed by a prognostic grid point model which solves the primitive equations of motion of the atmosphere in three dimensions with a time-step of two and a half minutes. It generates as output a full description of the changes to temperature, mean wind velocity and turbulence parameters at each grid point in the region investigated. A consequence of the approach is an inclusion of the natural wind shear that occurs in the convective boundary layer. This is concentrated near the surface and near the top of the mixing layer. Additional wind shear can be imposed by specifying the large scale 'thermal wind'.

The plume dynamics module. At each time-step the rise and initial dispersion of the pollutant plume from an arbitrarily located stack is computed using the wind and temperature data from the wind field module. The procedure of Briggs (1975) is followed. In stable conditions, a formula incorporating a 1/3 power dependence on initial buoyancy flux is used; in convective conditions a 3/5 power dependence on buoyancy flux is used (Weil, 1985).

The Lagrangian particle module. Particles are released at the final rise height with each particle 'weighted' by its fraction of emissions from the stack. The particles are then dispersed in the computed wind field by a random walk process: at each 1-minute time-step each particle is moved downwind a distance according to the local wind speed and direction. An additional displacement is given to each particle at each time step according to the local turbulence conditions. The means of relating turbulence conditions to the displacement of a particle is very complex and is the subject of current research.

CSIRO utilised LADM to predict the maximum groundlevel concentrations under fumigation and convective conditions.

2.4 AIR QUALITY CRITERIA

The Western Australian Environmental Protection Authority (EPA) is in the process of establishing an Environmental Protection Policy (EPP) for the Kwinana Region. The Draft EPP (EPA, 1989) proposes 1-hour average ambient standards and limits of sulphur dioxide for three policy areas. After reviewing the public comment on the Draft EPP, the EPA has indicated that it will be including medium (24-hour) and long (annual) term standards and limits into the final EPP. Table 2 presents a summary of the likely standards and limits.

The three air quality policy areas are described below:

- Area A-used mostly for industrial purposes;
- Area B-a buffer zone between industry and residential use; and
- Area C-the area beyond the buffer zone.

TABLE 2

PROPOSED STANDARDS AND LIMITS OF SULPHUR DIOXIDE
FOR KWINANA

	Standard (Desirable Level) ($\mu g/m^3$)	Limit (Never to be Exceeded) ($\mu g/m^3$)
1-Hour Average Sulphur Dioxide Concentrations		
Area A	700	1,400
Area B	500	1,000
Area C	350	700
24-Hour Average Sulphur Dioxide Concentrations		
Area A	200	365
Area B	150	200
Area C	125	200
Annual Average Sulphur Dioxide Concentrations		
Area A	60	80
Area B	50	60
Area C	50	60

The EPA currently recommends the utilisation of these standards and limits to determine the acceptability of industrial emissions of sulphur dioxide. The 1-hour average standard for residential areas of 350µg/m^3 is normally used as the primary indicator of acceptability.

The EPA has equated the Draft EPP standard to the 9th highest 1-hour average groundlevel concentration. The use of the 9th highest 1-hour average concentration is widely accepted as a means of eliminating extreme meteorological conditions for which model accuracy is known to be poor. Therefore, in terms of assessing the impact of pollutants, the 9th highest 1-hour average groundlevel concentration should be compared with the Draft EPP 1-hour standard for each of the policy areas. Compliance with the 1-hour average sulphur dioxide standards and limits would generally ensure compliance with the medium (24-hour) and long (annual) term averages.

3.0 MODELLING RESULTS

3.1 AUSPLUME AIR DISPERSION MODEL

The emissions scenario presented in Table 1 has been utilised to model the predicted groundlevel concentrations of sulphur dioxide resulting from the cumulative impact of WSL and AMC. Table 3 presents a summary of the AUSPLUME model results and indicates that the maximum predicted concentrations are below the proposed standards in every case.

Contours representing the predicted annual, maximum 24-hour, maximum 1-hour and 9th highest 1-hour average groundlevel concentrations are presented in Figures 2 to 5 respectively. The contours of the predicted annual averaged groundlevel concentrations of sulphur dioxide (Figure 2) show that the maximum predicted impact is expected to occur to the north-west of the WSL stacks. This figure also indicates that the impact of the AMC emissions is very small, as would be expected from the emissions information (Table 1)

TABLE 3

SUMMARY OF AUSPLUME AIR DISPERSION MODELLING RESULTS (CUMULATIVE IMPACT)

	Maximum Predicted Concentration *($\mu g/m^3$)*	*Residential Standard/Limit* *($\mu g/m^3$)*	
Annual Average	16.9	50.0	(Standard)
24-Hour Average	114.0	150.0	(Standard)
1-Hour Average	532.0	700.0	(Limit)
9th Highest 1-Hour Average	289.0	350.0	(Standard)

Figure 3 presents the contours of the maximum predicted 24-hour average groundlevel concentrations of sulphur dioxide over the modelled area. The maximum concentration of 114µg/m^3 was predicted to occur approximately 400m to the north-west of the WSL stacks.

Figure 4 presents the contours of the maximum predicted 1-hour average groundlevel concentrations of sulphur dioxide. The maximum concentration of 532µg/m^3 was predicted to occur approximately 2.0km to the north of the WSL stacks. The maximum predicted concentration is well below the likely residential 1-hour limit of 700µg/m^3.

The predicted 9th highest 1-hour average groundlevel concentrations of sulphur dioxide are presented in Figure 5. This figure shows that the likely residential standard of 350μg/m^3 is not predicted to be exceeded anywhere over the modelled grid.

3.2 CSIRO LAGRANGIAN AIR DISPERSION MODEL

Fumigation and convective conditions were modelled by CSIRO and the full report is presented in Appendix A. CSIRO utilised LADM and actual data collected by SECWA near Bunbury. These data consisted of vertical profiles of temperature, wind speed and direction for a number of different days. CSIRO selected a day that it considered to be conducive to poor air quality due to the strong thermal stability of the lower layers of the atmosphere.

Of the emission sources listed in Table 1, CSIRO modelled only the new stack (ie. SR-1 & SR-2 Kilns and SR-2 Drier) and the existing drier as they considered that the impact of the other sources would be negligible. The maximum predicted groundlevel concentrations of sulphur dioxide, as a function of time of day, for the new stack considered in isolation are presented in Table 4.

TABLE 4

PREDICTED MAXIMUM GROUNDLEVEL CONCENTRATIONS
OF SULPHUR DIOXIDE UNDER FUMIGATION AND CONVECTIVE CONDITIONS
NEW STACK IN ISOLATION

Time	*Maximum Predicted 1-hour Averaged Groundlevel Concentration ($\mu g/m^3$)*
0800	0
0900	0
1000	135
1100	690
1200	485

Table 4 indicates that when considered in isolation the combined emissions from the new stack are predicted to produce a maximum 1-hour average groundlevel concentration of sulphur dioxide of 690μg/m^3. This concentration is very close to the allowable limit (700μg/m^3) for residential areas and was predicted to occur at a distance of one kilometre from the stack.

Table 5 presents the maximum predicted groundlevel concentrations of sulphur dioxide as a function of distance for 1100hrs (ie. the time of the maximum predicted groundlevel concentration under the modelled conditions).

TABLE 5

PREDICTED MAXIMUM GROUNDLEVEL CONCENTRATIONS OF OF SULPHUR DIOXIDE UNDER FUMIGATION AND CONVECTIVE CONDITIONS AS A FUNCTION OF DISTANCE FOR 1100 HOURS

Distance (m)	1,000	2,000	5,000	10,000
Maximum 1-hour average groundlevel concentration of sulphur dioxide ($\mu g/m^3$). New source (SR-1 & SR-2 Kiln and SR-2 Drier) in isolation	690	440	220	85
Maximum 1-hour average groundlevel concentration of sulphur dioxide ($\mu g/m^3$). New Source (SR-1 & SR-2 Kiln and SR-2 Drier) and existing SR-1 Drier.	695	505	255	85

Table 5 indicates that the combined emissions from the new stack in conjunction with the emissions from the existing SR-1 Drier are predicted to produce a maximum 1-hour average groundlevel concentration of sulphur dioxide of $695\mu g/m^3$. This concentration is very close to the allowable limit ($700\mu g/m^3$) for residential areas. Calculations utilising convective scaling (see Appendix A) indicate that the acceptable residential standard of $350\mu g/m^3$ is predicted to be exceeded for distances of up to approximately three kilometres from the source.

The extreme nature of the vertical temperature profile utilised in this modelling results in a delay in the onset of fumigation, but not the magnitude of the predicted short-term groundlevel concentrations. The very stable vertical temperature profile results in slow growth of the well mixed layer. Under convective conditions the maximum predicted concentrations can be significantly affected by the mixing depth. For example, convective scaling has been used to show that doubling the mixing height from 300 to 600m results in a 60% reduction in the maximum predicted groundlevel concentrations at one kilometre downwind (see Appendix A). Therefore, less extreme conditions are likely to result in lower groundlevel concentrations.

4.0 FREQUENCY OF FUMIGATION AND CONVECTIVE CONDITIONS

The Bureau of Meteorology has conducted an analysis of meteorological data to determine the frequency and predictability of fumigation and convective conditions and its report is presented in Appendix B.

Data obtained at Perth Airport were used in this study and assumed to be representative of the Bunbury/Capel area. After an analysis of the synoptic and topographic conditions it was concluded that the long-term climatological conditions experienced in the two areas were likely to be similar. Further, it was concluded that on the large majority of the occasions of particular interest, Perth Airport data would provide a good approximation to conditions around the Bunbury area.

Vertical soundings of both wind and temperature are generally conducted at around 0700 Western Standard Time (WST). The exception to this occurs during the summer months when the morning balloon flight is conducted at 0600 WST. The variation of wind speed and wind direction with height are monitored every six hours, while the vertical temperature profile is monitored every twelve hours.

Wind data for a height of approximately 500m above the ground have been used for the analysis of climatological conditions. The Bureau of Meteorology considers that the climatologies for this level are broadly representative of lower levels, although the wind speeds would generally be expected to be lower nearer the ground.

It was estimated that at least one temperature inversion was likely to occur below 600m on about 60% of days in October-November, rising to around 85% of days from April to September. Ground-based inversions are particularly frequent during winter, and are the dominant inversions in the lowest several hundred metres during those months. It is likely that more ground-based inversions form in the summer months than are apparent in the data as they may have been partly eroded by ground heating prior to sonde time. Ground-based inversions are recorded on approximately 80% of mornings from May to August. The occurrence of inversions with bases between 200m and 600m altitude shows a strong peak during the warmer months. They are particularly infrequent during June and July. This annual variation may be due partly to the influence of solar heating of the ground prior to sonde time in the summer period, but also reflects the general tendency of synoptic factors to lead to weaker stability in the lower atmosphere in the cooler months.

About 16% of all inversions based below 600m are at least 400m thick, while 3% are over 600m thick. This correspond to there being a ground-based inversion more than 400m thick on about 9% of days, and in excess of 600m thick on about 2% of days. These thick inversions are concentrated heavily between January and April.

Within the five years of data analysed, there were approximately 110 days per year that had inversions which satisfied the following criteria: base height below 600m; at least 200m thick; and an air temperature increase through the inversion of at least 1°C per 100m. These inversions were most frequent between January and April, and least frequent in October. The frequency of occurrence in many calendar months varied considerably between years. Such variations were greatest in the winter months.

The occurrence of major inversions (ground-based inversions at least 250m thick; all elevated inversions at least 200m thick; and an average air temperature increase through the inversion of at least 1°C per 100m) is strongly related to specific synoptic weather systems. As such, the occurrence of major inversions should be predictable. The key feature of the synoptic patterns is an anticyclone which is typically centred either south of the continent or over the land mass to the east or north-east of the Perth-Bunbury area. The resultant air flow over that region is typically from the east to north-east in summer and north-east to north during the winter. Frequently the flow is accentuated by the presence of a low pressure trough near the west coast.

Examination of 32 major inversion events from 1988, supplemented with a further 22 from the winter of 1989, demonstrated these features of the wind field. Estimates of variations in mixing depth through the day on each of these occasions suggests that depths between 250m and 600m can occasionally persist for over 4 hrs during winter and more than 8 hrs in the summer months. Within the 54 cases analysed, two such winter events and four summer events were identified. The available information indicates that on occasions the surface mixed layer may remain less than 600m deep throughout the day. Such conditions may lead to periods with high concentrations of pollutants at ground level from an elevated source. Wind directions in the lowest few hundred metres of the atmosphere may not necessarily change greatly during such periods. Generally the major inversions are associated with north-east to easterly winds at a height of 300m.

Within the five years of data analysed, the Bureau of Meteorology found that there were a total of 35 inversions that were of similar severity to the inversion modelled by CSIRO. Therefore, the analysis of the upper air data indicates that an average of seven severe inversions occur per year. These severe inversions could result in groundlevel concentrations of a similar order as the worst-case concentrations predicted by CSIRO. However, the data analysis also indicates that the occurrence of these severe (and major) inversions can be forecast from the synoptic situation.

5.0 SUMMARY OF AIR DISPERSION MODELLING

The AUSPLUME air dispersion modelling of the final emissions scenario for the proposed WSL expansion has shown that the groundlevel concentrations of sulphur dioxide under normal conditions are not predicted to exceed any of the standards or limits. However, CSIRO modelling of fumigation and convective conditions has shown that the predicted groundlevel concentration of sulphur dioxide may approach the residential limits of 700$\mu g/m^3$ within one kilometre of the source under some conditions. Further, groundlevel concentrations in excess of 350$\mu g/m^3$ are predicted to be exceeded for approximately three kilometres from the source. The CSIRO estimated that the conditions associated with convective and fumigation conditions could occur on or about 7% of all days at Capel.

The Bureau of Meteorology has estimated that on average there are 27 days per year (approximately 7% of all days) where a major inversion exists below a height of 600m. Of these, an average of 7 days per year have inversions that were of similar severity to the inversion modelled by CSIRO (ie. for 28 April 1982) during their worst-case analysis. Generally the major inversions are associated with north-east to easterly winds.

The occurrence of major inversions is strongly related to specific synoptic weather systems. The key feature of the synoptic patterns is an anticyclone which is typically centred either south of the continent or over the land mass to the east or north-east of the Perth-Bunbury area. Therefore, the occurrence of major inversions should be predictable due to this strong relationship.

WSL plan to establish a management procedure to reduce the mass emission rate of sulphur dioxide when atmospheric conditions may result in groundlevel concentrations of sulphur dioxide exceeding the standard or limit (ie. under fumigation and convective conditions). This procedure could involve the Bureau of Meteorology providing a forecast of conditions that may result in groundlevel concentrations approaching the standard and limit.

All of the modelling undertaken within this report has assumed that the height of the new stack will be 110m and that the emissions from the SR-1 Kiln will be ducted to this stack. However, at this stage WSL have not made a firm commitment on the final height of the new stack or the plant configuration. The magnitude of the AUSPLUME modelling results indicate that it may be possible to decrease the height of the new centrally ducted stack and still meet the air quality objectives. In terms of convective conditions, CSIRO state that the predicted groundlevel concentrations are strongly dependent on the pollutant emission flux, the height of the convective mixing layer and the convective velocity scale. The groundlevel concentrations have a lesser dependence on the effective emissions height (ie. stack height plus plume rise). As such, it is not expected that small decreases in the height of the new stack would result in significant increases in the predicted groundlevel concentrations.

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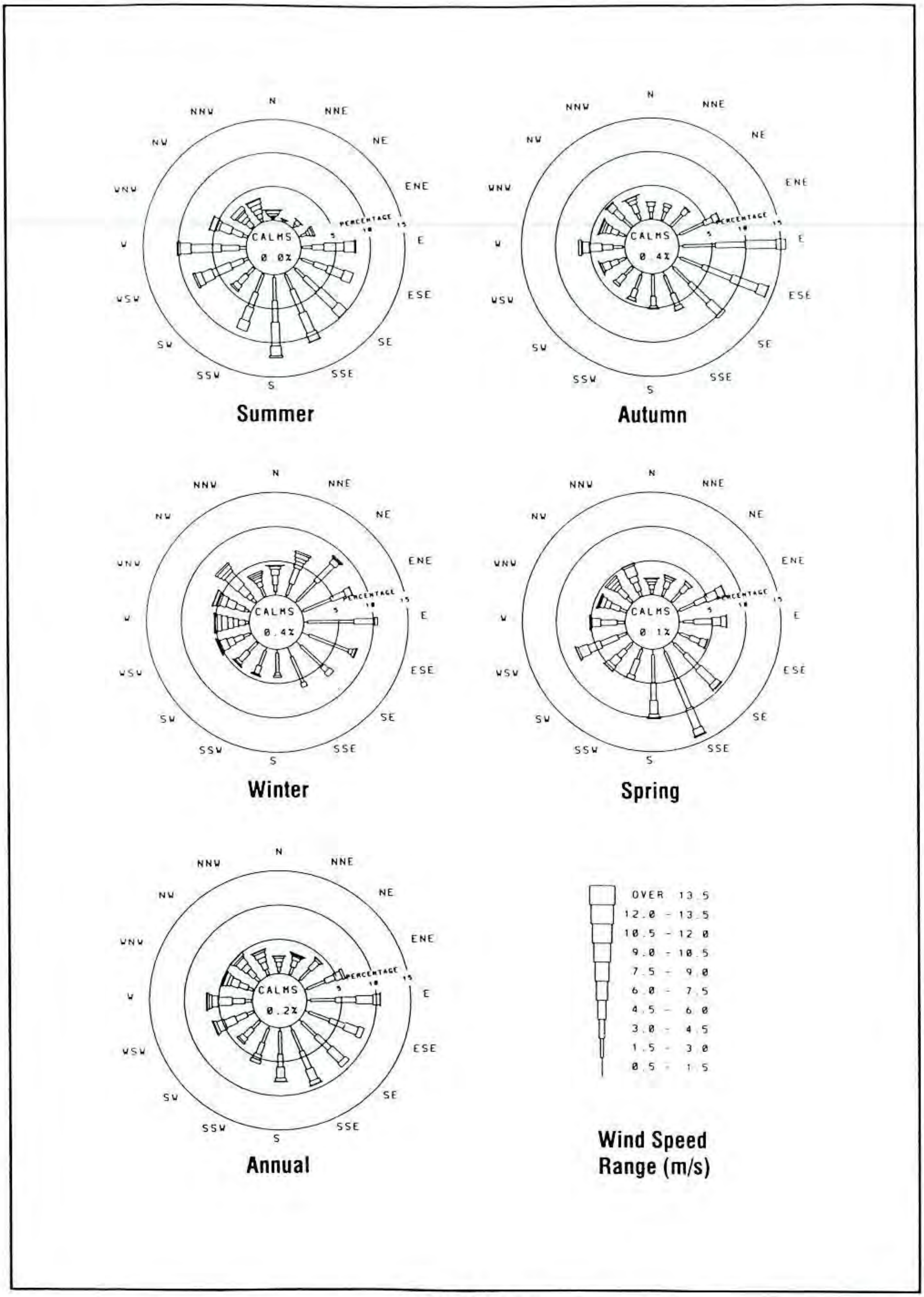
* * *

Respectfully submitted
DAMES & MOORE

B.P. Bell
Senior Environmental Scientist

BB/14365-022-071/DK:144-3538

Figures

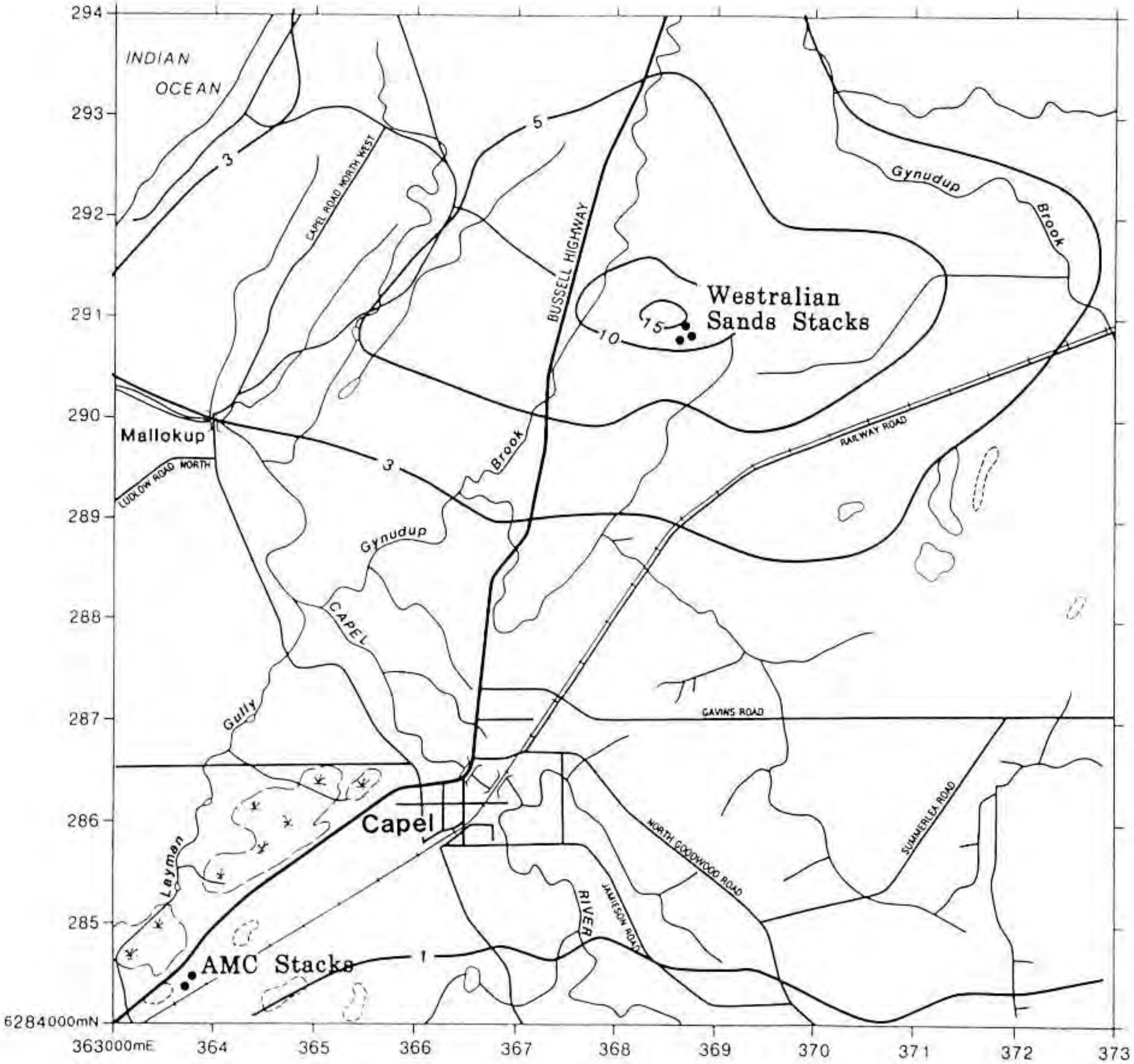


WIND ROSES

GLEN IRIS METEOROLOGICAL STATION

FIGURE 1

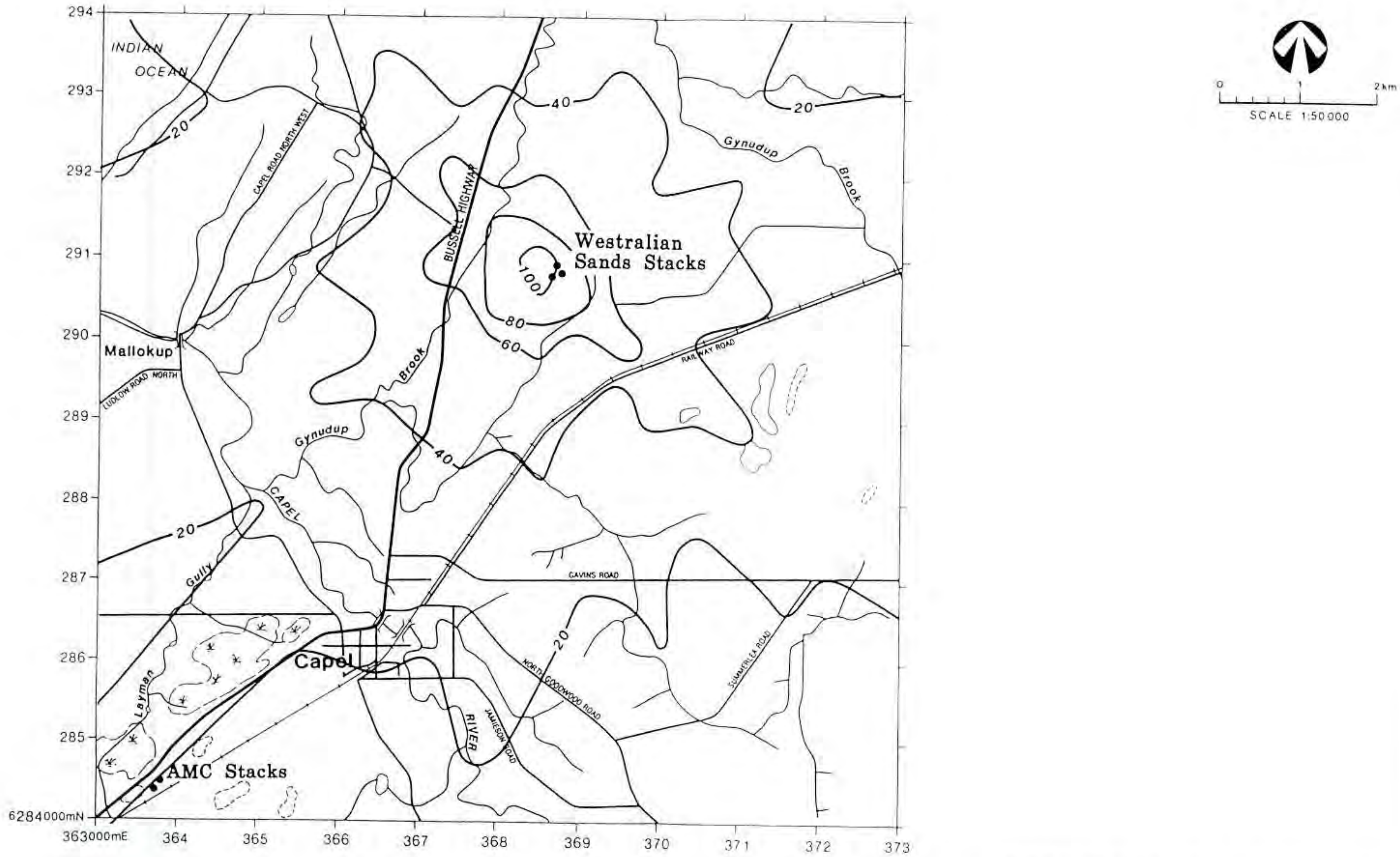
DAMES & MOORE



PREDICTED ANNUAL AVERAGE GROUNDLEVEL CONCENTRATIONS OF SULPHUR DIOXIDE (ug/m^3)

JOB No 14365-022-071		DATE
PREPARED BY	BB	05/02/92
APPROVED BY	BPGW	17/6/92

FIGURE 2
DAMES & MOORE

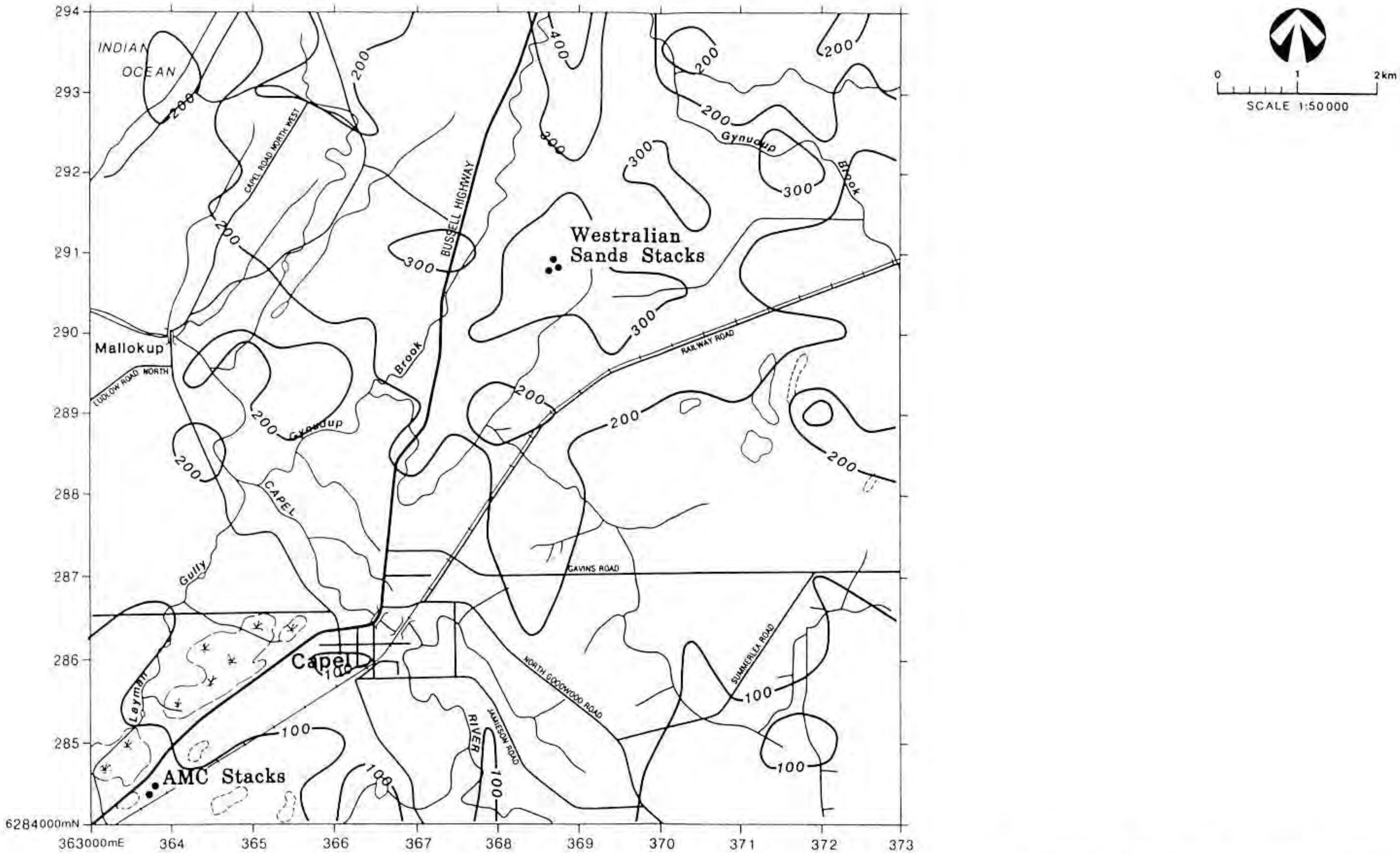


PREDICTED MAXIMUM 24-HOUR AVERAGE GROUNDLEVEL CONCENTRATIONS OF SULPHUR DIOXIDE (ug/m^3)

JOB No. 14365-022-071		DATE
PREPARED BY	BB	05/02/92
APPROVED BY	B.F.Gee	17/6/92

FIGURE 3
DAMES & MOORE

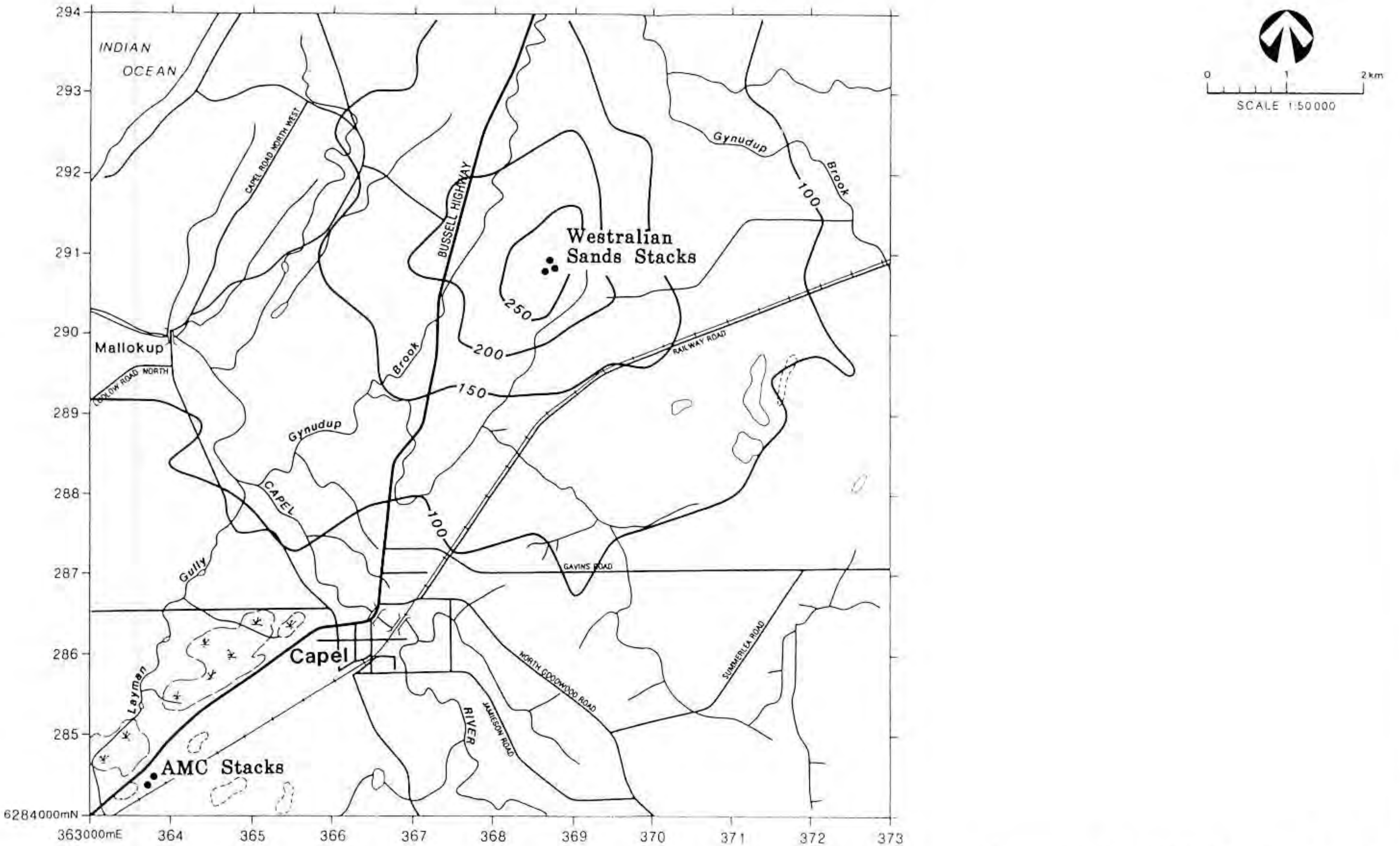
[redacted]



PREDICTED MAXIMUM 1-HOUR AVERAGE GROUNDLEVEL CONCENTRATIONS OF SULPHUR DIOXIDE (ug/m^3)

JOB No. 14365-022-071		DATE
PREPARED BY	BB	05/02/92
APPROVED BY	B P Bcl	17/6/92

FIGURE 4
DAMES & MOORE



PREDICTED 9th HIGHEST 1-HOUR AVERAGE GROUNDLEVEL CONCENTRATIONS OF SULPHUR DIOXIDE (ug/m^3)

JOB No. 14365-022-071		DATE
PREPARED BY	BB	05/02/92
APPROVED BY	B. r. bell	17/6/92

FIGURE 5
DAMES & MOORE

Appendix A

APPENDIX A

STUDY OF FUMIGATION AND CONVECTIVE MIXING
WESTRALIAN SANDS NORTH CAPEL SYNTHETIC RUTILE PLANT.

by

P.C. Manins and P.J. Hurley
CSIRO Division of Atmospheric Reaserch

Study of Fumigation and Convective Mixing

Westralian Sands North Capel

Synthetic Rutile Plant

P.C. Manins, P.J. Hurley

Environmental Consulting and Research Unit

Division of Atmospheric Research

CSIRO

PMB 1 Mordialloc 3195

Australia

CSIRO Ref: SB/1/151 18 May, 1992

Study of Fumigation and Convective Mixing Westralian Sands North Capel Synthetic Rutile Plant

P.C. Manins, P.J. Hurley

Environmental Consulting and Research Unit

Division of Atmospheric Research, CSIRO

18 May, 1992

Introduction

Dames & Moore (WA) are carrying out an air environment study for Westralian Sands Limited (WSL) North Capel Synthetic Rutile Plant (SRP), located 20 km south of Bunbury (WA). This is in support of a proposal to build a second SRP next to the existing plant, combining some emissions into a single stack with better dispersion characteristics than the existing plant.

CSIRO Division of Atmospheric Research has been asked by WSL to apply its numerical modelling skills to the morning fumigation and daytime convective mixing problems. We have developed a sophisticated simulation system that builds on the approach of Deardorff and Willis (1982)[1] but utilizes the latest research in applying Lagrangian particle dispersion to air pollution problems.

The work reported here covers the following:

- Application of the CSIRO Lagrangian Atmospheric Dispersion Model to the important SRP sources.
- Predictions of the ground level concentrations (glcs) of SO_2 at various distances from the site on a day conducive to poor air quality due to morning fumigation and convective mixing, and for which the WA EPA has obtained upper air data on winds and temperatures.
- Prediction of the maximum glcs of SO_2 on a day that is expected to approximate worst-case conditions based on the results of AUSPLUME modelling by Dames & Moore.

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[1]Deardorff, J. and Willis, G., 1982: *Atmospheric Environment*, 16, 1159-1170

Morning Fumigation and Convective Mixing

During the night the atmosphere near the ground can become thermally stable due to long-wave radiation cooling. The sky must be mostly cloud-free for this to occur. The plume from the proposed SRP at North Capel would not then mix to the ground, being held aloft at high concentrations in the stable air. Also in such conditions, it is common for considerable shear in both wind speed and direction to exist between the ground and plume level. This is demonstrated in the data obtained by WA EPA at Bunbury on 28 April and 18 November 1982 during special campaigns[2].

Once the sun's heating of the ground begins, a mixing layer grows upward from the surface. Within an hour the mixing would extend to the height of the plume from the proposed SRP and would mix it to the ground. Since the plume would be usually quite narrow then, having diluted little in the night air, the SO_2 concentrations due to the initial mixing to ground level would be high over an area of a few hectares. The high concentrations would only last for half an hour or so, and decrease as the mixing layer grows beyond the height of the plume. The plume from the smaller SR-1 Drier would mix to the ground earlier.

This process, the so-called 'morning fumigation' event, is known to occur in other regions in Western Australia. A particularly well-known situation is the Kalgoorlie region. Morning fumigation is the cause of the worst pollution conditions in Kalgoorlie/Boulder and has been a major problem for the operation of the gold roasters on the eastern edge of the city.

Following fumigation, the highly convective turbulence continues to mix the plumes to the ground rapidly. The concentrations then experienced are lower than at the peak of morning fumigation, but occur over a larger area and can persist for some time.

Modelling System for Morning Fumigation and Convective Conditions

The standard approach for modelling morning fumigation has been to use the procedure of Turner (1970)[3]. However, this has been shown to overestimate ground level concentrations and to locate incorrectly the distances of impact. The current best approach is to use the CSIRO Lagrangian Atmospheric Dispersion Model (LADM)[4]. It compares very well with the much more limited model of Deardorff and Willis, which utilizes their results from water tank simulations of the fumigation process. Their model is able to reproduce the tank data very well; it is presently the standard against which any alternative procedure should be judged. However, in reality, atmospheric conditions are much more complex than can be simulated in the laboratory. The biggest inadequacies of the Deardorff and Willis model are its poor description of dispersion in the real boundary layer, its neglect of plume dynamics as the boundary layer develops in the morning, and its unsatisfactory treatment of wind

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[2] Rayner,K. and Watson, I. 1991: *Atmospheric Environment*, 25a, 1427-1436

[3]Turner, D., 1970: *Workbook of Atmospheric Dispersion Estimates*, USEPA, AP-26.

[4]Physick, W., Noonan, J., Manins, P., Hurley, P. and H. Malfroy, 1991: 'Application of coupled prognostic windfield and Lagrangian dispersion models for air quality purposes in a region of coastal terrain' Proceedings of 19th International Technical Meeting of NATO-CMS on Air Pollution Modelling and Its Application. Ierapetra, Crete, Greece, 29 September - 4 October 1991

shear through the dispersing plume as the boundary layer grows through the levels of the plume.

LADM overcomes practically all the identified problems of the Deardorff and Willis approach. The model has three modules:

The wind field module. The winds in the growing morning boundary layer are computed by a prognostic grid point model which solves the primitive equations of motion of the atmosphere in three dimensions with a time step of two and a half minutes. It generates as output a full description of the changes to temperature, mean wind velocity and turbulence parameters at each grid point in the region investigated. A consequence of the approach is an inclusion of the natural wind shear that occurs in the convective boundary layer. This is concentrated near the surface and near the top of the mixing layer. Additional wind shear can be imposed by specifying the large-scale 'thermal wind'.

The plume dynamics module. At each timestep the rise and initial dispersion of the pollutant plume from an arbitrarily located chimney is computed using the wind and temperature data from the wind field module. The procedure of Briggs (1975)[5] is followed. In stable conditions, a formula incorporating a 1/3 power dependence on initial buoyancy flux is used; in convective conditions a 3/5 power dependence on buoyancy flux is used (Weil, 1985)[6].

The Lagrangian particle module. Particles are released at the final rise height with each particle 'weighted' by its fraction of emissions from the chimney. The particles are then dispersed in the computed wind field by a random walk process: at each 1-minute timestep each particle is moved downwind a distance according to the *local* wind speed and direction. An additional displacement is given to each particle at each timestep according to the *local* turbulence conditions. The means of relating turbulence conditions to the displacement of a particle is very complex and is the subject of current research. The actual details of the method utilized are described by Hurley and Physick (1991, 1992)[7].

Modelled Meteorological Conditions for the Study

Scenario 1. This is an observed case: 28 April 1982. It was a day conducive to poor air quality due to morning fumigation and convective mixing. The surface wind speed reached 2.5 ms^{-1} after 10.00 am. The mixing layer grew slowly, suppressed by the remarkably strong thermal stability of the lower layers of the atmosphere. Plume height was not reached until around 10.00. A significant northerly jet was evident, with winds of 7 ms^{-1} above 500 m. Table 1 shows the initial conditions that have been used to simulate this day.

---

[5]Briggs, G.A. (1975). Plume rise predictions. Chapter 3 in: Lectures on Air Pollution and Environmental Impact Analyses. Ed: D.A. Haugen. American Meteorological Society. pp59-105.

[6]Weil, J.C. (1985). Updating applied diffusion models. *J. Cl. App. Meteor.*, **24**, pp1111-1130.

[7]Hurley, P. and Physick, W. (1991). A fumigation model incorporating a Lagrangian particle approach. *Atmospheric Environment*, **25A**, 1313-1325.
Hurley, P. and Physick, W. (1992). A skewed, homogeneous, Lagrangian particle model for convective conditions. Submitted to *Atmospheric Environment*.

Table 1. Meteorological conditions for LADM

SCENARIO 1	
Gradient wind speed	5 m/s at the surface, increasing to 7 m/s by 300 m, steady to 400 m, and decreasing to 4 m/s at 800 m
Wind direction	45^o up to 100 m, backing to 0^o at 300 m and above
Potential temp. profile	0.090 K/m to 100 m, decreasing to 0.030 K/m at 300 to 400 m, decreasing to 0.002 at 800 m

SCENARIO 2	
Gradient wind speed	3 m/s at all heights
Wind direction	0^o at all heights
Potential temp. profile	0.090 K/m to 100 m, decreasing to 0.030 K/m at 300 to 400 m, decreasing to 0.002 at 800 m

Scenario 2. The AUSPLUME predictions by Dames & Moore of the highest 50 ground level concentrations at North Capel predict that they occur between 0600 and 1200 on 27 separate occasions for the modelled year. This is consistent with morning fumigation and convective mixing being the cause. Thus 54 % of the top 50 predictions of high ground level concentrations of SO_2 due to the SRP are expected to be due to these processes - this is over 7 % of all days in a year.

As Table 2 shows, almost half of the top-50 occasions were in autumn, when lighter winds were favoured (average of 2.7 ms^{-1} during the cases identified). This is the same as in the Scenario 1 case. We have chosen to model conditions that result in a 1.5 ms^{-1} surface wind for all morning hours, with no shear in wind direction. The same temperature gradient with height as in Scenario 1 is used, as it is already an extreme example of the result of clear-sky nocturnal cooling. The initial conditions are again given in Table 1.

Table 2. Analysis of top 50 AUSPLUME predictions

	Summer	Autumn	Winter	Spring	
Number of occasions	9	14	5	3	Total 31
Min Wind (ms^{-1})	0.8	1.0	1.1	1.4	ave 0.8
Ave Wind (ms^{-1})	3.0	2.7	2.3	1.9	ave 2.6
Max Wind (ms^{-1})	5.9	4.9	4.0	2.6	ave 5.9

Scenario 2 is chosen to approximate worst case convective conditions. It is a variant of Scenario 1. Since the temperature profile for the first case is already rather extreme, we merely omit the observed wind shear - see Table 1.

Emission Characteristics

There are two adjacent sources at the SRP: the SR-1 Drier, and the proposed SRP which is a combination of SR-1 & 2 kiln plus SR-2 drier. We ignore a nearby minor source (the North Capel Drier) and two remote sources (the AMC Sources 1 and 2) on the grounds that their contributions to ground level concentrations of SO_2 will be negligible.

Runs were performed for both Scenarios 1 and 2. Only for Scenario 1 were both the new SRP and the SR-1 drier included. For the second Scenario we have estimated the small contribution to glcs by the drier on the basis of convective scaling. The emissions characteristics in Table 3 were used. All runs began at 05.00 Local Solar Time with a solar declination for 28 April.

Table 3. Operating Conditions for SRP Emitters

	SR-1 drier	New SRP
Stack height (m)	35.5	110
Exit temperature (°C)	60	110
Stack Diameter (m)	1.0	2.5
Volume flux (m^3s^{-1})	6.3	72.2
SO_2 emission (kgs^{-1})	0.015	0.215

Results from LADM for the two scenarios

Maximum glcs for New SRP

Figure 1 shows the predictions of the footprint of ground level concentrations for the new SRP alone for Scenario 1, at the time of maximum impact, at two resolutions. Figure 2 is the same for Scenario 2. The peak hourly average glc for Scenario 1 occurs at hour ending 1100 and is 690 $\mu g\ m^{-2}$ at a distance of 1000 m from the Plant. For Scenario 2 the peak is at the same time, with a level of 1020 $\mu g\ m^{-2}$ at a distance of 750 m. Table 4 shows how the peaks vary with time. For Scenario 2 we are unable to report a value at 1200 because of the lack of computer time. However it is clear that the maximum glc was declining slowly, as for Scenario 1.

Table 4. Maximum glcs predicted by LADM - new SRP alone

TIME	0800	0900	1000	1100	1200
Scenario 1	0	0	135	690	485
Scenario 2	0	0	395	1020	?

Glcs with distance at the Time of Maximum

Table 5 shows predicted maximum glcs for the new SRP with distance at 1100 hr for the two Scenarios. The impact of the SR-1 drier is also included as indicated above.

Table 5. Maximum glcs at 1100 hr predicted by LADM

DISTANCE: (m)	1000	2000	5000	10000
SCENARIO 1				
New SRP	690	440	220	85
New+Drier	695	505	255	85
SCENARIO 2				
New SRP	805	510	285	135
New + Drier	870	550	305	150

Predicted Impacts at 5 km and 20 km Distances

Capel is a distance of 5 km to the SSW of the SRP; Bunbury is 20 km to the N. Under different meteorological conditions it is possible that these places could be impacted by the SRP. Table 6 shows the predictions for the two Scenarios, with wind *direction*ignored.

Table 6. Maximum Impacts by Time (to nearest 25 μg m^{-3})

5 km Downwind	0800	0900	1000	1100
SCENARIO 1	<25	25	50	200
SCENARIO 2	<25	25	175	300
20 km Downwind	0800	0900	1000	1100
SCENARIO 1	<25	<25	50	50
SCENARIO 2	<25	<25	150	125

Discussion

The results obtained here are rather extreme (this is, of course, an objective of the present work) and we do not know how frequently they would be experienced in practice. The conditions modelled in Scenario 1 were indeed observed, but the temperature profile is, by any measure, unusually strong. This has the effect of delaying the onset of morning fumigation but not the predicted ground level concentrations. Later in the morning, once fully developed convective conditions are established, three factors change:

- The predicted concentrations are dependent on average mixing height instead of the transient height to which the plume rose earlier in the morning.
- High concentrations no longer extend to large distances downwind.
- High concentrations can be experienced at a given place for long periods, not just for the brief time that morning fumigation occurs.

These factors can be studied numerically or, more simply, by using convective scaling arguments[8]. As is shown in the Appendix, convective scaling is able to reproduce most of the numerical modelling results given here reasonably well. The common difference between LADM and scaling is also evident: LADM usually predicts *lower* concentrations because it correctly accounts for wind shear. The effects of increased mixing layer and of fully developed convection into the afternoon are also shown in the Appendix: a doubling of the mixing height from 300 m to 600 m causes a predicted reduction of glcs by over 60 % at a distance of 1000 m downwind. As another example, the Appendix considers a situation where the emission from the SRP is reduced by 50 % and the stack height is also reduced: from 110 m to 75 m. Then the predicted maximum glc is reduced by 40 %, and at distances of 2 km and beyond, the concentrations are predicted to be less than 200 μg m^{-3}.

Conclusions

The predicted peak concentrations for Scenario 1 are large. The values would decay only slowly during the day under suitable convective conditions. The frequency of

[8]See, *eg*, Briggs, G.A., 1988: Chapter 2 in *Lectures on Air Pollution Modeling*, AMS, Boston, USA.

occurrence of these conditions is unknown, but related convective conditions are expected to occur on about 7 % of all days at Capel. The concentrations predicted for Scenario 2 are 50 % higher than for Scenario 1, but would be much rarer, and in fact may never occur.

There would be little benefit in considering alternative stack heights for the new SRP in isolation. The most important variable is the flux of sulfur dioxide: the glcs are proportional to the emitted flux. An example in the Appendix shows that a 50 % reduction in emissions and a reduced stack height can give a worthwhile reduction in glcs and save on construction expenses. It is unclear whether the reduction is adequate for licensing purposes.

Invoking a buffer zone is a possibility. But the zone would have to extend for at least two kilometres around the SRP to encompass all levels of 500 μg m^{-2} or greater in all conditions under the proposed operating conditions of the SRP. A distance of about a kilometre may be all that is needed if emissions are halved.

Appendix. Convective Scaling

In convective conditions, ground level concentrations due to an elevated plume are strongly dependent on the emission flux, Q, the height of the convective mixing layer, z_i, and the convective velocity scale, w_*. There is a lesser dependence on effective emission height, z_e (*ie* chimney height plus plume rise height).

Define

> Convective velocity scale, $w_* = (z_i \cdot gH_v / \rho C_p)$ where H_v is the surface heat flux, g is acceleration due to gravity, ρ is air density, C_p is specific heat.
>
> Convective distance, $X = (xw_* / Uz_i)$.
>
> Cross-wind integrated dimensionless concentration, $C^y = Uz_i \int Cdy / Q$ where C is the time-average concentration[9], Q the emission strength.

The maximum ground level concentration is $C^y_{max} = 1 + 0.5(z_i / z_e)$. The distance to the maximum is given by $X_{max} = 2z_e / z_i$.. At dimensionless distances of $X \geq 1 - 2$ the plume will be well mixed in the vertical and the cross-wind integrated dimensionless concentration, C^y, decreases to unity.

---

[9]The averaging time is the natural convective eddy timescale, which is of order ten to thirty minutes. In stationary conditions the expected concentrations will be the same for one-hour averages.

We have $C = \frac{QC^y}{Uz_i\sqrt{2\pi}\sigma_y}\exp\left(-\frac{1}{2}\left(\frac{y-y_P}{\sigma_y}\right)^2\right)$. As a simplification, put $C^y = 1$ and note

that for $X > 1 - 2$ (well-mixed conditions), $\sigma_y = 0.5z_i\left(\frac{xw_*}{Uz_i}\right)^{2/3}$.

Thus $C(x) = \frac{2Q}{\sqrt{2\pi}\left(U^{1/2}z_i^2 xw_*\right)^{2/3}}$

Case 1. If we take as a representative set of conditions, $U = 3\ ms^{-1}$, $w_* = 1\ ms^{-1}$, $z_i = 300$ m, then $X = x/900$. For the new SRP, $z_e = 200$ m, $Q = 215\ gs^{-1}$, we predict a peak glc at $X_{max} = 1.3$, *ie* at $x = 1200$ m, with a value of $C^y_{max} = 1.75$, so $C_{max} = 895\ \mu g\ m^{-3}$.

At different distances downwind, we have:

x (m)	2,000	5,000	10,000
C ($\mu g\ m^{-3}$)	370	205	130

Case 2. If the mixing height were 600 m, the predicted peak concentration still occurs at a distance of 1200 m downwind, but the value is reduced to $C_{max} = 485\ \mu g\ m^{-3}$.

At different distances down wind we have:

x (m)	2,000	5,000	10,000
C ($\mu g\ m^{-3}$)	145	75	50

Case 3. Consider the same meteorological conditions as in Case 1 and an alternative operating scenario: reduce emissions from the SRP by 50 % to 108 g s^{-1} and reduce the stack height to 75 m. Then $z_e = 165$ m, and the distance to maximum glc is reduced to 990 m, the peak concentration becomes 540 $\mu g\ m^{-3}$, and the behaviour with distance down wind is:

x (m)	2,000	5,000	10,000
C ($\mu g\ m^{-3}$)	175	95	60

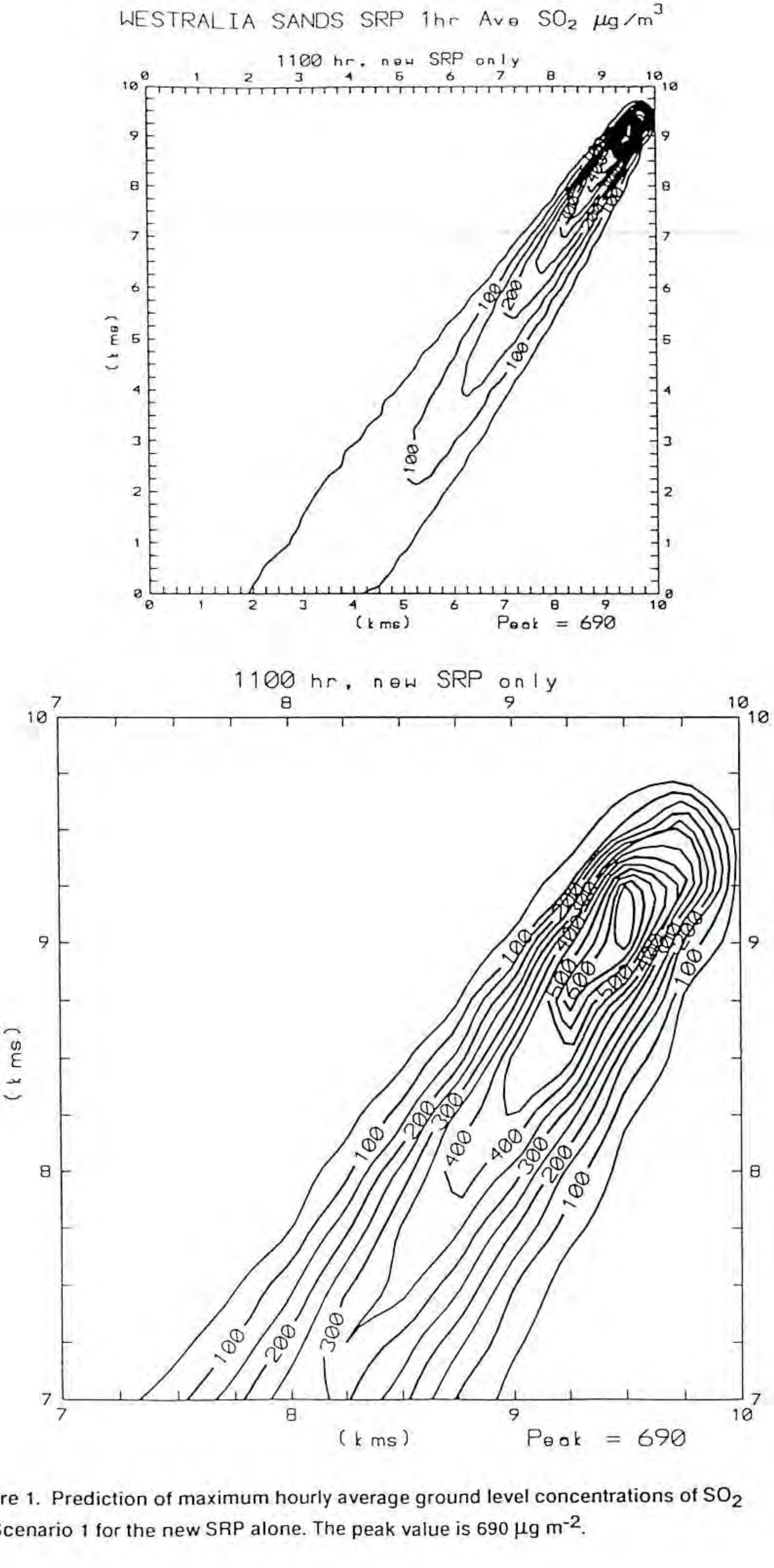

Figure 1. Prediction of maximum hourly average ground level concentrations of SO_2 for Scenario 1 for the new SRP alone. The peak value is 690 $\mu g\ m^{-2}$.

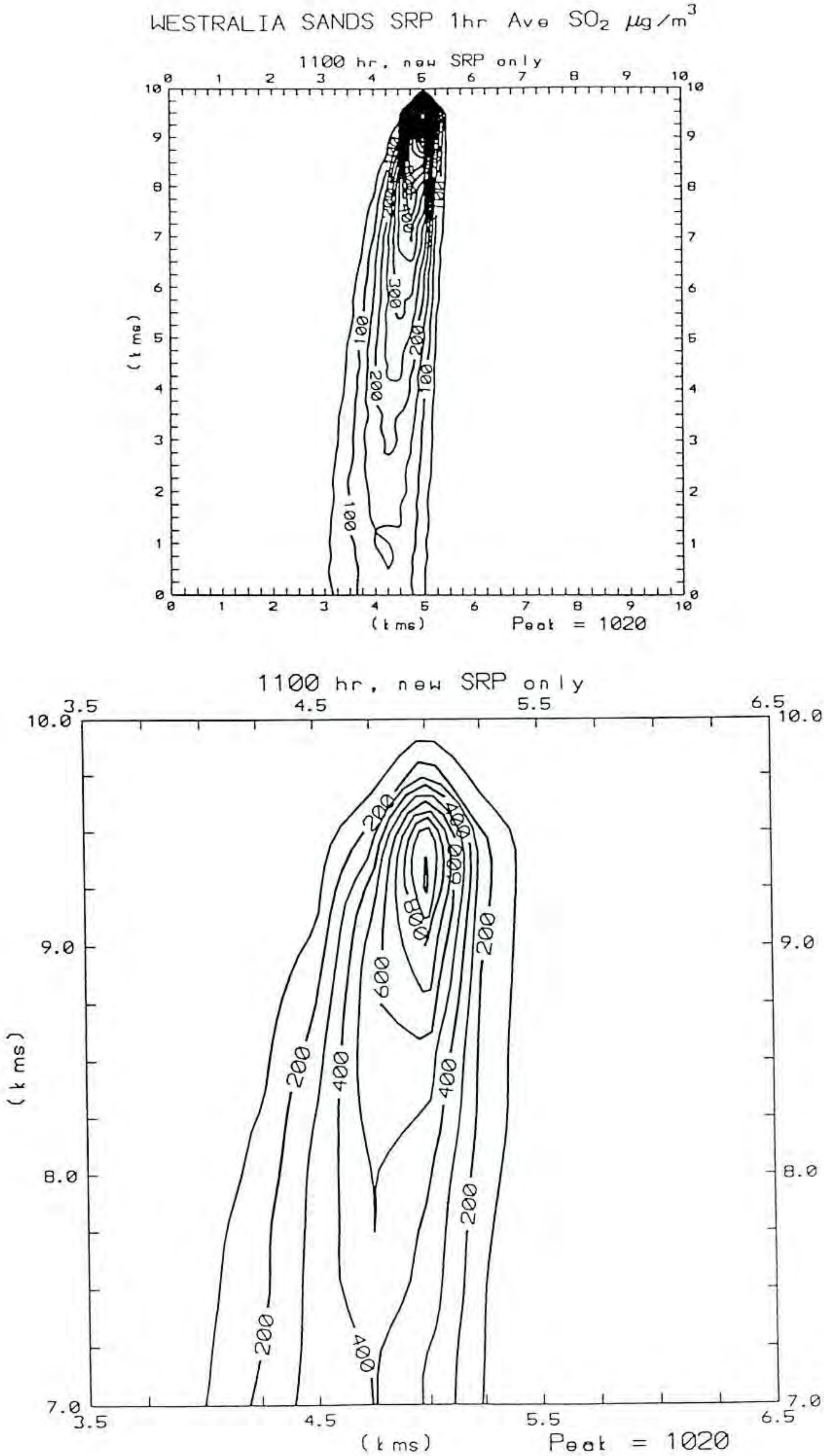

Figure 2. Prediction of maximum hourly average ground level concentrations of SO_2 for Scenario 2 for the new SRP alone. The peak value is 1,020 $\mu g\ m^{-2}$.

Appendix B

APPENDIX

SAMPLE TABLES PRODUCED IN THE
CLIMATOLOGICAL ANALYSIS OF
LOW LEVEL TEMPERATURE INVERSIONS
WITH BASES BELOW 2000 METRES

PRODUCED BY CONSULTING SERVICES SECTION, NATIONAL CLIMATE CENTRE, BUREAU OF METEOROLOGY, AUSTRALIA.

TEMPERATURE INVERSION THICKNESS .VS. LAPSE RATE .VS. FREQUENCY OF OCCURRENCE

STATION NAME : PERTH
WMO STATION NO. : 94610
STATION ELEVATION : 17.0 M.
STATION LATITUDE : 31 DEG. 55 MIN. SOUTH
STATION LONGITUDE : 115 DEG. 58 MIN. EAST

PERIOD OF RECORD : 1987 - 1991

MONTH / SEASON : ALL COMBINED

FLIGHT TIME : 2200 UTC

LAPSE RATE (C/KM)

THICKNESS (M)	0 - 5	5 - 10	10 - 15	15 - 20	20 - 25	25 - 30	30 - 35	35 - 40	40 - 45	45 - 50	50 - 55	55 - 60	60 - 65	65 - 70	70 - 75	75 OR MORE	TOTAL
0 - 100	81	53	63	35	24	9	11	16	10	5	1	4	2	1	1	8	324
100 - 200	222	203	157	107	76	62	36	26	23	19	8	4	1	2	1	0	947
200 - 300	155	144	110	123	84	39	18	5	3	0	0	0	1	0	0	0	682
300 - 400	89	102	105	60	40	15	6	0	0	0	0	0	0	0	0	0	417
400 - 500	55	57	62	40	11	2	2	0	0	0	0	0	0	0	0	0	229
500 - 600	33	40	24	8	2	0	0	0	0	0	0	0	0	0	0	0	107
600 - 700	18	31	13	0	0	0	0	0	0	0	0	0	0	0	0	0	62
700 - 800	11	16	2	0	0	0	0	0	0	0	0	0	0	0	0	0	29
800 - 900	3	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
900 - 1000	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
1000 - 1100	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
1100 - 1200	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
1200 - 1300	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1300 - 1400	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1400 - 1500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1500 - 1600	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1600 - 1700	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1700 - 1800	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1800 - 1900	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1900 - 2000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2000 OR MORE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	671	656	536	373	237	127	73	47	36	24	9	8	4	3	2	8	2814

PRODUCED BY CONSULTING SERVICES SECTION, NATIONAL CLIMATE CENTRE, BUREAU OF METEOROLOGY, AUSTRALIA.

TEMPERATURE INVERSION BASE HEIGHT .VS. LAPSE RATE .VS. FREQUENCY OF OCCURRENCE

STATION NAME : PERTH
WMO STATION NO. : 94610
STATION ELEVATION : 17.0 M.
STATION LATITUDE : 31 DEG. 55 MIN. SOUTH
STATION LONGITUDE : 115 DEG. 58 MIN. EAST

PERIOD OF RECORD : 1987 - 1991

MONTH / SEASON : ALL COMBINED

FLIGHT TIME : 2200 UTC

LAPSE RATE (C/KM)

BASE HEIGHT (M)	0 - 5	5 - 10	10 - 15	15 - 20	20 - 25	25 - 30	30 - 35	35 - 40	40 - 45	45 - 50	50 - 55	55 - 60	60 - 65	65 - 70	70 - 75	75 OR MORE	TOTAL
GROUND BASED	163	192	212	164	128	49	29	25	21	14	3	3	4	1	1	2	1011
1 - 100	10	18	19	4	8	3	1	1	1	0	1	1	0	0	0	0	67
100 - 200	13	30	36	19	6	6	5	4	1	0	0	0	0	0	0	0	120
200 - 300	14	32	22	24	8	9	3	0	0	0	0	1	0	0	0	0	113
300 - 400	22	36	35	24	10	13	3	0	1	0	0	0	0	0	0	1	145
400 - 500	29	35	18	23	12	5	4	1	2	0	0	0	0	1	0	1	131
500 - 600	19	23	20	13	10	5	6	1	0	1	0	0	0	0	0	0	98
600 - 700	11	18	15	12	6	4	2	1	0	1	0	0	0	0	0	0	70
700 - 800	14	12	4	5	5	2	1	0	1	0	0	0	0	0	0	0	44
800 - 900	19	17	6	5	0	1	2	1	1	0	0	0	0	0	0	0	52
900 - 1000	25	17	6	6	3	1	1	3	1	0	0	0	0	0	0	2	65
1000 - 1100	17	18	10	3	4	1	2	0	0	0	0	0	0	0	0	0	55
1100 - 1200	25	17	12	8	8	1	1	0	0	1	0	0	0	0	0	0	73
1200 - 1300	23	19	15	10	4	8	0	1	1	1	0	1	0	0	0	0	83
1300 - 1400	38	19	12	3	8	2	1	0	2	1	0	0	0	0	0	0	86
1400 - 1500	40	26	23	6	4	2	2	3	0	1	0	0	0	0	0	1	108
1500 - 1600	34	31	11	7	3	3	1	2	1	0	3	0	0	1	0	0	97
1600 - 1700	27	21	15	11	1	5	1	1	1	0	0	3	0	0	1	1	88
1700 - 1800	37	32	21	8	5	4	4	2	1	1	1	0	0	0	0	0	116
1800 - 1900	44	23	13	3	1	2	4	1	0	3	0	0	0	0	0	0	94
1900 - 2000	42	25	11	10	3	1	0	0	1	0	0	0	0	0	0	0	93
TOTAL	671	656	536	373	237	127	73	47	36	24	9	8	4	3	2	8	2814

PRODUCED BY CONSULTING SERVICES SECTION, NATIONAL CLIMATE CENTRE, BUREAU OF METEOROLOGY, AUSTRALIA.

TEMPERATURE INVERSION BASE HEIGHT .VS. THICKNESS .VS. FREQUENCY OF OCCURRENCE

STATION NAME : PERTH
WMO STATION NO. : 94610
STATION ELEVATION : 17.0 M.
STATION LATITUDE : 31 DEG. 55 MIN. SOUTH
STATION LONGITUDE : 115 DEG. 58 MIN. EAST

PERIOD OF RECORD : 1987 - 1991

MONTH / SEASON : ALL COMBINED

FLIGHT TIME : 2200 UTC

THICKNESS (M)

BASE HEIGHT	0	100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	TOTAL
(M)	100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	OR MORE	
GROUND BASED	152	317	222	155	87	44	19	11	1	1	2	0	0	0	0	0	0	0	0	0	0	1011
1 - 100	14	29	9	6	3	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	67
100 - 200	17	39	15	22	14	6	4	3	0	0	0	0	0	0	0	0	0	0	0	0	0	120
200 - 300	10	31	29	25	14	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	113
300 - 400	12	38	50	24	9	8	2	1	0	1	0	0	0	0	0	0	0	0	0	0	0	145
400 - 500	7	49	42	18	8	6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	131
500 - 600	12	30	31	6	12	2	0	3	1	1	0	0	0	0	0	0	0	0	0	0	0	98
600 - 700	3	25	21	10	6	1	2	0	1	0	0	1	0	0	0	0	0	0	0	0	0	70
700 - 800	6	11	13	7	2	1	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	44
800 - 900	4	17	13	9	3	0	4	0	0	2	0	0	0	0	0	0	0	0	0	0	0	52
900 - 1000	6	23	20	5	3	3	3	1	1	0	0	0	0	0	0	0	0	0	0	0	0	65
1000 - 1100	4	18	14	11	3	2	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	55
1100 - 1200	5	20	23	9	10	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	73
1200 - 1300	7	32	20	9	12	2	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	88
1300 - 1400	10	34	19	13	3	2	4	0	1	0	0	0	0	0	0	0	0	0	0	0	0	86
1400 - 1500	8	40	22	20	10	3	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	108
1500 - 1600	3	35	30	15	8	4	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	97
1600 - 1700	8	41	18	14	5	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	88
1700 - 1800	12	38	30	17	6	10	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	116
1800 - 1900	12	46	22	5	5	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	94
1900 - 2000	12	34	19	17	6	2	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	93
TOTAL	324	947	682	417	224	107	62	29	8	6	2	1	0	0	0	0	0	0	0	0	0	2814

APPENDIX B

METEOROLOGICAL FACTORS AFFECTING DISPERSION OF ELEVATED, BUOYANT PLUMES - BUNBURY AREA

by

R. Tapp and P. Lainio

Bureau of Meteorology, Perth

METEOROLOGICAL FACTORS AFFECTING DISPERSION OF ELEVATED, BUOYANT PLUMES - BUNBURY AREA

Report for:
Westralian Sands Limited, Capel

Report by:
Bureau of Meteorology, Perth
Climate and Consultative Services Section
in conjunction with
Special Services Unit

Investigators:
R. Tapp, P. Lainio

June 1992

METEOROLOGICAL FACTORS AFFECTING DISPERSION OF ELEVATED, BUOYANT PLUMES - BUNBURY AREA

SUMMARY

A survey has been carried out of available data collected routinely by the Bureau of Meteorology which has relevance to diffusion of an elevated plume in the Capel area south of Bunbury. Particular attention has been given to wind and atmospheric stability conditions in the lowest 600 m of the atmosphere. This region was considered to be of greatest importance for the study.

No data suitable for such a study are available from the Bunbury region. Data obtained at Perth Airport were therefore used and assumed to be representative of the area of interest. From synoptic and topographic considerations it was concluded that the long term climatologies of conditions in the two areas were likely to be similar, and that, on the large majority of the occasions of particular interest, Perth Airport data would provide a good approximation to conditions around the Bunbury area. The validity of these assumptions is discussed.

Vertical soundings of both wind and temperature are made at around 0700 WST except during the summer months when summer time has been adopted in other states. The morning balloon flight is then conducted at 0600 WST. Winds are monitored every six hours, temperatures every twelve hours.

Wind data for a height around 500 m above ground were readily available for analysis of climatological conditions. The climatologies for this level are considered to be broadly representative of lower levels also, although the wind speeds would generally be expected to be lighter nearer the ground.

The climatological distributions of winds at 0600/0700 WST indicate that east to north-east winds dominate during summer. During the cooler months, the winds become predominantly westerly. Northerly winds are of some importance also. The summer easterlies tend to be fairly strong at Perth Airport. They are likely to be enhanced on some occasions following passage over the Darling Scarp. At Bunbury in such situations the winds would be expected to be lighter both because any topographic enhancement would be less and because Bunbury would be nearer to the ridge axis where synoptic winds would be weaker anyway. By early afternoon the wind distributions show winds around 500 m which are generally weaker. Sea breezes are apparent in the warmer months.

Winds of 3 m s^{-1} or less at around 500 m at 0600/0700 WST are uncommon during the warmer months, especially between January and March. Of the winds which do occur in this speed range: east to southeast winds are apparent through most of the year, but are more frequent in the cooler months; southerlies are more frequent during spring and early summer; winds in a broad band between northwest and northeast occur during the cooler months.

The mean stability of the lowest 1000 m of the atmosphere is greater during the first half of the year than the second.

It was estimated that at least one temperature inversion was likely to occur below 600 m on about 60% of days in October-November, rising to around 85% of days from April to September. Ground-based inversions are particularly frequent during winter, and are the dominant inversions in the lowest several hundred metres during those months. It is likely that more ground-based inversions form in the summer months than are apparent in the data: they may have been partly eroded by ground heating prior to sonde time. Ground-based inversions are recorded on approximately 80% of mornings from May to August. The occurrence of inversions with bases between 200 m and 600 m altitude shows a strong peak during the warmer months. They are particularly infrequent during June and July. This annual variation may be due partly to the influence of solar heating of the ground prior to sonde time in the summer period, but also reflects the general tendency of synoptic factors to lead to weaker stability in the lower atmosphere in the cooler months.

About 16% of all inversions based below 600 m are at least 400 m thick, while 3% are over 600 m thick. These figures apply to both ground-based and elevated inversions. They correspond to there being a ground-based inversion more than 400 m thick on about 9% of days, and in excess of 600 m thick on about 2% of days. These thick inversions are concentrated heavily between January and April.

Many thick inversions tend to be relatively weak. Likewise, those with the strongest stability tend to be ground-based and shallow. However, some do occur which are both relatively thick and relatively strong. These were investigated in some detail.

Within the five years of data analysed all the inversions were identified which satisfied the following criteria: base height below 600 m; at least 200 m thick; and an air temperature increase through the inversion of at least 1°C per 100 m. On approximately 110 days within each year at least one such inversion occurred. Such occasions were most frequent between January and April, and least frequent in October. The frequency of occurrence in many calendar months varied considerably between years. Such variations were greatest in the winter months.

The occurrence of major inversions is strongly related to specific synoptic weather systems. The key feature of these patterns is an anticyclone which is typically centred either south of the continent or over the land mass to the east or northeast of the Perth-Bunbury area. The resultant air flow over that region is typically from the east to northeast in summer and northeast to north during the winter. Frequently the flow is accentuated by the presence of a low pressure trough near the west coast.

Examination of 32 major inversion events from 1988 supplemented with a further 22 from the winter of 1989 demonstrated these features of the wind field. Estimates of variations in mixing depth through the day on each occasion suggested that depths between 250 m and 600 m can occasionally persist for over 4 hr during winter and more than 8 hr in the summer months. Within the 54 cases analysed 2 such winter events and 4 summer events were identified. The available information indicates that on occasion the surface mixed layer may remain less than 600 m deep throughout the day. Such conditions may lead to periods with high concentrations of pollutants at ground level from an elevated source. Wind directions in the lowest few hundred metres of the atmosphere may not necessarily change greatly during such periods.

Within the five years of data there were 17 ground-based inversions which were at least 280 m thick through which the air temperature increased by at least 10°C. There were a further 11 through which the temperature increase was between 9°C and 10°C, all of which were at least 320 m thick. In addition there were 7 inversions based above 200 m and at least 300 m thick, 3 of which had temperature increases in excess of 10°C through them, the other 4 had increases of 9-10°C. The ground-based inversions occurred throughout the year, although most were recorded between January and June; the elevated ones all occurred between October and February. Such occasions are indicative of the extreme of low level stability likely to be encountered.

1. Introduction

This study aims to examine features of the lower atmosphere in the Bunbury area which are of relevance to dispersal of material released in a plume from an elevated source.

The initial attention is focussed on climatological distributions of:

- o winds near 500 m altitude; and
- o temperature inversions evident at low levels.

Temperature inversions are layers of very stable air which severely inhibit vertical diffusion of airborne material. They are so called because the air temperature increases with increasing altitude through them, whereas the temperature normally decreases with height. The wind to be examined approximates that near the ceiling height of the plume, and affects both the rate of diffusion of the plume in the downwind direction and the direction in which the plume moves.

Particular attention has been focussed on the period from around sunrise to about midday. This period is considered to be that when serious and possibly persistent air quality problems are most likely to arise. During this time any low level temperature inversion which may have developed through stabilisation of the boundary layer overnight will be eroded gradually by solar heating of the ground. This may lead to two particular situations in relation to a plume which had been released overnight into a stable atmosphere and experienced little dilution:

- o fumigation of the plume may occur when the developing mixed layer of air deepens to the level where it entrains the plume.
- o the mixed layer continues to grow beyond the axis of the plume, but upward diffusion remains limited because the plume is trapped by an elevated inversion at a slightly higher level.

In both situations parcels of the plume may be brought to ground level in largely undiluted form.

In such situations the wind speed may also be light within the inversion and the developing mixed layer adjacent to the surface, limiting horizontal diffusion. On some occasions the inversion may not be broken completely. In such circumstances it is possible that trapping could persist throughout the day.

Data from Perth Airport have been used almost exclusively in these investigations. Extensive meteorological data are not available from Bunbury: the nearest locations where suitable data for such a study exist are Perth Airport and Albany. It is considered that of the two Perth Airport would better represent conditions at Bunbury. These matters are discussed in the following Section. In Section 3 the wind distribution near 500 m is examined. Section 4 investigates the frequency of occurrence and characteristics of temperature inversions. Individual occasions on which inversions likely to be of particular relevance to the matter in question are considered in some detail in Section 5.

2. Climatic Conditions in the Bunbury Area and the Applicability to That Area of Upper Air Data from Perth Airport

In this Section average conditions in the Bunbury area and at adjacent locations are examined. Lengthy records of surface meteorological observations are available from both Perth Airport and Bunbury Post Office. Long term averages of upper air data exist from Perth Airport and Albany for shorter periods. Details of the lengths of the data records used to provide the climatological information discussed in this Section are provided in Table 1.

2.1. Surface Temperatures

The average minimum temperature for the year as a whole is approximately 0.5°C cooler at Perth Airport than at Bunbury. However, this difference varies through the year from Perth having average minima approximately 0.8°C warmer than those at Bunbury during summer to being about 1°C cooler in winter.

The picture changes shortly after sunrise, however. Average 0900 WST temperatures in all months are higher at Perth Airport, by amounts ranging from about 0.2°C in winter to about 1.5°C in summer.

Over the year as a whole the average maximum temperature is approximately 2.3°C warmer at Perth Airport than at Bunbury. The difference ranges from approximately 3.5°C in mid-summer to approximately 0.8°C in mid-winter. The day to day variability of the maximum temperature is also greater at Perth, particularly in summer.

2.2 Rainfall

The long term rainfall distributions at Perth City and at Bunbury show effectively no differences. Data are available for at least 100 years in both areas.

2.3 Surface Winds

a. 0900 WST

The distributions of the prevailing winds at the two locations at 0900 WST differ slightly.

- o Both sites indicate the occurrence of land breezes overnight and persisting into the early morning. These winds come from the east to southeast at Bunbury and from the east to northeast at Perth Airport. They tend to be fairly light, occurring when the synoptic pressure gradient is weak.
- o Wind directions attributable to the synoptic pressure gradient are similar at the two locations. Winds with an easterly component tend to dominate during the warmer months, those with a westerly component during winter. These winds may have a northerly or southerly component in all months.

Wind speeds, divided into the following three categories, less than 3.0 m s^{-1}, 3.0-8.4 m s^{-1}, and 8.5 m s^{-1} or greater, show the following features:

- o Winds of less than 3 m s^{-1} are recorded much more often at Bunbury than at Perth Airport, although the difference is only small during the winter months.
- o There is a corresponding decrease in the frequency with which winds of between 3.0 and 8.4 m s^{-1} are reported.
- o Winds of 8.5 m s^{-1} or more are recorded more frequently at Bunbury than at Perth Airport between May and August, in particular. These strong winds mostly come from directions between southwest and north, with northwest being most common.

The average frequencies of occurrence of winds in the three speed ranges are presented in Table 2a.

Examination of wind directions associated with light winds only is complicated due to the high occurrence of "calm" conditions at 0900 WST at Perth Airport. From April to September approximately 25% of all days have "calm" conditions, so that no wind direction is reported. The figure is lower in the warmer months, typically 10%. This compares with "calm" conditions being reported on no more than 7% of days, on average, in any month at Bunbury. However, similar features to those reported above are apparent when wind speeds of less than 3 m s^{-1} only are analysed. At 0900 WST land breezes are apparent at both locations, with the directions mentioned above. Winds associated directly with the synoptic pressure gradient are mostly from the east in summer and the southwest in winter.

b. 1500 WST

At 1500 WST the wind distributions at the two locations bear many similarities. Winds from the west to southwest are common throughout the year. These winds dominate at Perth Airport from September to December, in particular. They are likely to be a combination of sea breezes and synoptic flow. These winds also extend into the northwest sector at Bunbury. A significant number of occurrences of winds from the north are apparent during winter. The strong northwesterly winds are again evident at Bunbury during the cooler months. Winds from the east to southeast also occur frequently at both places. They are particularly apparent from January to April, but remain of importance in months either side of this period. (This is less so at Perth Airport in the September to December period because of the dominance of west to southwest winds in these months, as mentioned above.)

Broad distributions of the wind speeds at the two sites in each month are presented in Table 2b.

Low wind speeds are uncommon at Perth Airport at 1500 WST from October to January, in particular. At 1500 WST light winds from the southwest to west are common at Bunbury in all months. These may be frequently associated with sea breezes. It appears that when sea breezes reach Perth Airport they are mostly stronger than 3 m s^{-1} or do not arrive until after 1500 WST. Light northeast winds are apparent at Perth Airport in the winter months, which may indicate persistence of land breezes. Light synoptic winds are mostly from the east to southeast in the summer months and have a significant westerly component during winter.

2.4 Upper Level Temperatures

Average temperatures at the 900 hPa pressure level (about 1000 m above ground) are approximately 3°C warmer at Perth than at Albany over the year as a whole. The average difference varies from about 5°C in mid-summer to about 1°C in mid-winter. Perth remains warmer at around 1500 m. The overall average difference is again approximately 3°C, ranging from around 4°C in mid-summer to about 1°C in mid-winter.

If a linear gradient of average temperature with latitude is assumed, then on average the air near 1000 m above the Bunbury region would be about 1.5°C cooler than that above Perth, varying from about 2.5°C in mid-summer to 0.5°C in mid-winter. Considering this in conjunction with the differences in surface air temperatures discussed above, the average stability over the lowest 1000 m of the atmosphere is slightly greater at Perth than at Bunbury in the early morning. In fact, in January, for example, the average minimum temperature at Perth Airport is over 1°C colder than that near 1000 m, whereas at Bunbury the average minimum is 0.9°C warmer. Conditions in summer change rapidly shortly after sunrise, however. By 0900 WST the average surface temperature in January is 7.0°C warmer than the average minimum at Perth Airport and 5.6°C warmer at Bunbury (Table 3). This reflects the influence of the strong solar heating in summer when skies are frequently clear.

The mean lapse rate (change of temperature with height) above Perth Airport at sonde time is most stable between January and May, when it ranges between -1.6 and -2.0 °C km^{-1} compared with -2.8 to -4.0 °C km^{-1} between June and December. This matter is discussed further in Section 4.

It must be remembered, however, that conditions on individual days will rarely resemble the average. The temperature profile in the lowest several thousand metres typically consists of several layers with different lapse rates, some of which may be very stable with the temperature increasing with height.

2.5 Upper Level Winds

The mean vector wind at around 1000 m above Albany is very light from the northeast to northwest from January to March, and westerly through the rest of the year. At Perth, the mean vector wind is east to northeast from November to April and westerly through the winter.

2.6 Discussion of Climatological Features

Many of the features discussed above are indicative of the positions of the two monitoring sites relative to the adjacent ocean, which has a modifying effect on temperatures and results in earlier and more frequent arrival of sea breezes.

Thus, for example, the mean low level stability at Perth Airport early on summer mornings is greater than that estimated to exist over Bunbury. This may be attributed to the enhanced cooling of the surface overnight at the inland airport site relative to Bunbury Post Office, where the ocean has a greater moderating influence. The relative difference is likely to be less between Perth Airport and the Capel area, which is also a short distance inland.

It is of note that the mean stability of the surface to 900 hPa layer is greatest during the warmer months. This is despite the fact that sonde release time was approximately 0700 WST throughout the period used in this analysis. Thus, solar heating had had a much greater impact on the surface temperature during the summer months than during the winter. The average surface temperature at release time exceeds the average minimum temperature by 4.5°C in December compared with 1.6°C in August.

Some care must be taken when comparing the surface wind data from the two locations, since the observations from Bunbury described above were visual estimates made at the Post Office, whereas the station at Perth Airport is instrumented. Wind speeds are likely to be affected by this difference in monitoring method more than wind directions. However, the consistency of some of the different features of the wind distributions at the two sites noted above, both between months and between times of day, suggest that these differences in recorded winds cannot be attributed totally to the different methods by which the measurements were made.

Several of the features noted in the discussion of the wind field require some further comment.

- The differences in the directions of the land breezes reflects the different orientations of the coastline in the two areas.
- Strong northwest winds frequently occur ahead of approaching wintertime cold fronts. Their greater strength at Bunbury may indicate that synoptic pressure gradients in such circumstances are frequently stronger at the location further south. There may also be a contribution to the greater strength from the local topography causing channelling or deflection of the air stream and resulting in confluence in the wind field. A further factor which may contribute is that a northwest wind comes to the Bunbury

site immediately after a long passage over water, whereas a similar wind reaching Perth Airport has travelled over land for some distance and so has been slowed by the greater friction.

The differences between the mean upper winds at Perth and Albany reflect the mean location of the subtropical high pressure ridge. This ridge is generally located south of Perth during the summer but frequently is still north of Albany. The ridge is typically located south of the Bunbury area also in summer. However, being nearer the ridge axis Bunbury is likely to experience generally lighter winds during these months. There may be occasions when the ridge is located between Perth and Bunbury, in which case winds are likely to be westerly over Bunbury but easterly over Perth. They are likely to be light at both places, however. During winter the subtropical ridge is typically well north of Perth, and westerly flow prevails throughout southern Western Australia.

Overall, it is believed that data from Perth Airport are likely to provide a better representation of conditions near Bunbury than are observations from Albany. In the material which follows data from Perth Airport have therefore been assumed to be representative of conditions in the Bunbury area. This has involved two main assumptions:

- the wind above Perth is broadly similar to that likely to exist simultaneously above Bunbury.
- the shape of the temperature profile over the Bunbury area matches that monitored above Perth, particularly at the heights of most interest, between 200 m and 600 m.

These matters are discussed further in the following Sections.

3. Climatology of Winds Near 500 Metres

An analysis of typical winds observed at 950 hPa (near 500 m altitude) above Perth more detailed than that described in Section 2.5 was carried out.

Wind frequency distributions for an 18 year period (1971-1988) were produced. The distributions each month at approximately 0700 WST and 1300 WST have been analysed. (Balloon flight times were 0600 WST and 1200 WST from November to February, inclusive, in most instances.) These two times were considered to be the most relevant to the present study.

The 950 hPa data generally comprise the average wind through the second minute of the wind sounding. Assuming the nominal rate of ascent of the sounding balloon, this corresponds to the average conditions in the layer between about 300 m and 600 m altitude. Winds recorded at that level have been used because they are included in the Bureau of Meteorology's computerised data archive. While winds are normally recorded through the first minute of the flight also, they are not available in this form.

It is believed that the data from around 500 m are broadly applicable to conditions at lower elevations in most instances. This belief is based on the following considerations. In relation to the early sounding:

- o When the atmospheric stability is weak and when winds are strong the direction is likely to be approximately constant with height.
- o When the stability is strong the direction is more likely to change with height. However, occasions when the lower atmosphere is stable are also likely to give rise to local wind flows in relatively shallow layers near the ground. Along the coastal plain from Perth southward such flows are likely to have a strong easterly component. The synoptic conditions in which such flows are most likely to develop are those where the skies are clear with air flow over land. In the Perth-Bunbury area such conditions are mostly associated with synoptic winds which also have a strong easterly component.
- o If the inversion is ground based and shallow then flow associated with the synoptic pressure gradient is likely to exist at higher levels.
- o The wind speeds are likely to increase with height above the ground, in general.

By midday, two major possibilities exist:

- o Synoptic conditions prevail throughout the lowest 500 m of the atmosphere. Alternatively, a sea breeze may exist throughout that layer. In each instance there is likely to be little change in wind direction with height.
- o A sea breeze may exist in only a shallow layer and not extend throughout the lowest 500 m. Synoptic conditions then prevail at higher levels. Large differences in both wind direction and speed may result. The sea breeze has a westerly component, whereas sea breeze development occurs frequently when the synoptic flow has an easterly component. The presence of an elevated inversion may also produce decoupling of the wind in the vertical and lead to significant differences between winds at around 300 m and those near 500 m at times.
- o Again the wind speed is generally likely to increase with height.

Generally, it is believed that the overall climatological distribution of winds at around 500 m provides a good representation of the distribution of wind directions likely at lower levels. This is particularly so in relation to the 0700 WST data. By early afternoon there may be greater differences in the wind direction distributions at different heights during the summer months: the existence of shallow sea breezes may lead to there being more west to southwest winds and fewer broadly easterly winds at the lower elevations. Speeds are generally likely to be less at the lower heights. On individual occasions it is possible that significant changes in the wind with height will occur. Conditions in the two layers on specific occasions when strong inversions were present are discussed in Section 5.

The main wind directions observed around sunrise are as follows:

- During the summer months easterly and northeasterly winds dominate. They remain in evidence throughout the year, but with easterly winds being less prominent through the winter. Light winds (speeds less than about 5 $m\ s^{-1}$) from these directions tend to be fairly infrequent. Easterly winds, in particular, tend to be quite strong (speeds more than about 10 $m\ s^{-1}$).
- Northerly winds are also apparent in autumn and winter months. These winds are also mostly of moderate strength (speeds between about 10 and 20 $m\ s^{-1}$) or fairly strong.
- Westerly winds become increasingly evident from late autumn, and remain prominent throughout the winter and spring. Southwesterly winds also have some importance during this period, while northwesterly winds feature through the winter months. There is no clearly preferred speed range for winds from these directions.
- Southerly winds are more frequent from April to December. These winds tend to be light to moderate in strength.

Easterly winds in the early morning are likely to have their speeds enhanced frequently by flow over the Darling Scarp. This effect is likely to be greater at Perth Airport than at Bunbury, because the topography is more pronounced near Perth. Easterly winds may also be lighter at Bunbury because is nearer the axis of the high pressure ridge in such instances, and so the synoptic wind is likely to be slightly weaker.

By midday the wind regime differs in many respects. The main features of the wind distributions by early afternoon are as follows:

- Light to moderate easterly winds are apparent in most months, but are of only minor significance in winter.

- Light to moderate winds from between northeast and northwest become important during late autumn and winter.
- Light to moderate winds from the south to southwest occur frequently between November and April. From May to September-October the winds tend to be more from the southwest to northwest, and of similar strength.

The south to southwest winds during the warmer months are frequently attributable to sea breezes. On many occasions they have apparently replaced the northeast winds which were evident in the early morning distributions. In such events there would be a reversal of the wind direction in the lower levels during the morning.

Wind directions associated with very light winds only (3 m s^{-1} or less) have been examined specifically. This analysis is restricted to some extent because winds of such strengths near 500 m altitude are relatively infrequent in the early morning data. The occurrence of wind speeds in four broad ranges in both the 0600/0700 WST and 1200/1300 WST data are presented in Table 4. The directions associated with the light winds are shown in Table 5.

In the early morning data, light winds are particularly infrequent between January and March. The highest occurrences of such winds are:

- east-southeast winds from February to October.
- southerly winds between August and January.
- northwesterly winds, particularly in August and September.
- north to northeasterly winds between April and July.

Again, different wind directions are more prominent at 1200/1300 WST. The main ones evident are:

- winds in a broad range of directions between east and south, in all months but least prominent in winter.
- northerly winds from May to August.
- winds between south and west-southwest during the second half of the year.

4. Climatology of Low Level Temperature Inversions

Significant level temperature data are available in the Bureau of Meteorology's computerised data base only in the form of the original messages transmitted from the field stations. However, software has been prepared which decodes these messages and subjects them to quality control. The subsequent information has not been compared against the original soundings, so that some errors may remain. Any such errors are believed to be few and minor.

A second computer program which takes these significant level temperatures and identifies any layers in which the air temperature increases or is constant with height has also been developed. For each of these temperature inversions the following information is determined:

- o the height of the base of the layer.
- o the thickness of the layer.
- o the temperature change through the layer.
- o the rate at which the temperature increases with height through the layer (the lapse rate).

The frequencies of occurrence of the base height, thickness and lapse rate are then tabulated, both independently and in combination. Ground-based inversions are considered separately from those whose base is elevated. Base heights and thicknesses are grouped in 100 m increments, lapse rates are in increments of 5 °C km^{-1}.

All inversions whose bases are below 2000 m above ground are considered. When adjacent layers have temperature constant or increasing with height they are treated together as a single inversion, and the average lapse rate through the total combined layer is calculated. Individual soundings may have more than one inversion present in the lowest 2000 m. In such cases each inversion is treated separately.

Examples of some of the Tables generated in this analysis are presented in the Appendix.

As was discussed in Section 2, thermal conditions in the lowest several hundred metres above the Bunbury area may be different from those prevailing above Perth Airport. The greatest differences are likely to occur in the lowest 100 m or so of the atmosphere, and the differences are likely to be less at Capel than at Bunbury. It has therefore been assumed that at the heights of particular interest, above about 200 m, the shape of the profile at Perth is representative of that at Bunbury; that is, the changes in temperature between levels is the same even though the absolute temperatures at each level may differ slightly between the two locations.

This assumption is justified as follows:

- o The lower atmosphere is apparently more stable on average at Perth Airport than at Bunbury, particularly during summer. Because the Airport is further inland greater stabilisation of the near-surface air overnight takes place in that area than occurs at Bunbury.
- o The surface air temperature also warms more rapidly after sunrise at the Airport.
- o This indicates that differences in the temperature profiles at the two places occur largely close to the ground, most likely below about 100 m. In other words, any ground-based inversion is stronger adjacent to the surface at the airport.
- o Capel is further inland than is Bunbury, so that some of the relative differences between Perth Airport and Bunbury would be offset.
- o On the occasions which are of most interest the synoptic conditions affecting the Perth and Bunbury regions are likely to be very similar. This assumption is supported by some of the investigations carried out in this study, which are discussed in Section 5.

Any modifications to the traces to allow for diurnal changes, for example, have been made using surface temperatures which are also from Perth Airport and so are compatible with the sounding.

Temperature inversions with bases between about 200 m and 600 m are considered to be of greatest importance in the present context. Advice from Westralian Sands Limited indicates that the equilibrium plume height is rarely likely to be lower than about 250 m. On the other hand, if the inversion base is higher than 600 m the mixed layer below it is likely to be sufficiently deep that pollutants brought to ground level will have been diluted below critical levels. Particular attention has therefore been focussed on inversions in the above range in this study.

The initial investigations of inversions were carried out using the climatological analysis of all inversions with bases within 2000 m of ground in the five-year period 1987 to 1991.

Approximately 8% of days have no inversion in this height range. Such days are most frequent between May and November (Table 6). Of the remaining days, there are 8 to 9 inversions recorded which are based below 2000 m per 5 days, on average. That is, more than one inversion is frequently recorded in the lower part of a sounding.

The frequency distribution of base heights is multimodal:

- o There is a strong ground-based peak.
- o Another broad maximum exists between about 100 m and 600 m.
- o There is a clear minimum between about 700 m and 800 m.
- o Another broad maximum exists for base heights above about 1400 m.

The frequency of ground-based inversions shows a strong peak in the winter months, and a minimum in October and November (Table 6).

Specific figures regarding the occurrence of inversions with bases below 600 m only are not available. However, some impression of their frequency can be gained using details from the more extensive analysis.

- o The frequency of occurrence of ground-based inversions provides an initial estimate of the total frequency of occurrence of all low level inversions. This indicates that at least one third of days are affected from October to January, rising to about 80% in May to August.
- o Many of the elevated inversions which have bases below 600 m are likely to be the remains of ground-based inversions which developed overnight but which have been partly eroded by sonde time. This is so in summer particularly.
- o If it is assumed that it is unlikely that any sounding will contain two inversions with bases below 200 m, the minimum likely frequency of occurrence of inversions based below 600 m increases to about 50% of days from October to January, increasing to about 85% of days in May to August.
- o The frequencies of inversions with bases 200-600 m above ground show a strong summer maximum and winter minimum, suggesting again that many of these inversions in summer are the first encountered above ground and may also be the remains of nocturnal ground-based inversions.
- o In some instances a sounding will contain more than one inversion with its base below 600 m. Such occasions are likely to be infrequent, certainly much less than the figure given above for all inversions with bases below 2000 m. However, the frequencies of all inversions based below 600 m indicate that multiple inversions at those levels certainly occur between February and September.
- o Making some allowance for the occurrence of multiple inversions below 600 m, it is possible to make a final estimate of the likely occurrence of days with at least one inversion at those levels. These estimates suggest that about 60% of days will be so affected from October to December, about 70-75% of days in January to March, and between 80% and 90% of days in each of the other months, on average.

Details of these estimates are presented in Table 6.

Situations in which more than one inversion exists in the lowest few hundred metres of the atmosphere are likely to be important for the diffusion of an elevated plume. Typically, a surface-based inversion might be present, with an elevated inversion based at several hundred metres. Depending on the thickness of each, the plume may initially be either trapped in the lower inversion or able to mix between the two stable layers. In the first case, it would be fumigated as the first layer was eroded. In the second case, the surface would be unaffected until after the surface stability was eroded completely. In both scenarios, the plume would then be trapped below the elevated inversion while it remained.

For all inversions based below 2000 m, inversion thicknesses are mostly between 100 m and 300 m. About 15% of inversions are over 400 m thick, and about 4% exceed 600 m. Of inversions based below 600 m, 16% are at least 400 m thick and 3% more than 600 m. Many of these are surface-based, and are likely to be eroded fairly rapidly. Those which are elevated may be of greater concern.

Because ground-based inversions were treated separately in the climatological analysis, it is possible to determine greater detail about their typical features. Table 7 presents the frequencies of occurrence of ground-based inversions which were at least 400 m thick. Approximately 9% of days had such inversions. This figure exceeded 15% from February to April, and was 5% or less in June and October-December. Over half of those days occurred between January and April. Around 2% of days had ground-based inversions which extended to at least 600 m. Around 70% of those days occurred between January and April.

These figures correspond to 16% of all ground-based inversions extending to at least 400 m and about 3% extending beyond 600 m. More than 20% of ground-based inversions evident in soundings between January and April exceed 400 m in depth, while 15% or less were of such thickness in other months. The minimum frequency was 4% in June.

Two ground-based inversions extended to beyond 1000 m.

Many thick inversions are relatively weak. Likewise, inversions with very strong stability tend to be shallow. Most of those very stable ones are less than 200 m thick. A high percentage of the strongest inversions with bases below 600 m are also surface-based: about 80% of inversions with lapse rates of greater than 5°C per 100 m and base heights less than 600 m were ground-based. However, of all inversions which had bases below 600 m several were identifiable in the climatological analysis which had lapse rates of 3.0-3.5°C per 100 m and were between 300 m and 500 m thick.

These various findings provide some insight into the feature noted in Section 2.4 that the mean stability in the lowest 1000 m of the atmosphere is greatest in the first half of the year. In winter there is a high frequency of ground-based inversions, but they are frequently fairly shallow. Above this near-surface stability there are many fewer inversions. In the summer and autumn elevated inversions are much more common in the lowest kilometre.

Many of these matters are discussed further in the following Section.

5. Conditions Associated With Major Low Level Temperature Inversions

5.1 Preliminary Remarks

Two different methods have been used to investigate the occurrence of major low level inversions, the situations in which they occur and the meteorological conditions associated with them.

Firstly, in the process of generating the overall climatology of inversions discussed in the previous Section, details were listed regarding individual inversions which simultaneously satisfied several specified criteria. These criteria were:

- o the base of the inversion was no more than 600 m above the ground.
- o the inversion was at least 200 m thick.
- o the mean rate at which the temperature increased through the inversion was at least 1°C per 100 m.

The three criteria in combination were considered to broadly specify inversions which were likely to be of importance at heights between approximately 200 m and 600 m above ground, and so affect upward diffusion of plumes at those levels. This approach provided an objective assessment of the occurrence of these major inversions over a five-year period. Statistics of the information so produced regarding these inversions were generated. These data are discussed in Section 5.2.

Independently of this, a subjective assessment was undertaken. Diagrams depicting the temperature traces on each morning were inspected visually for one complete calendar year, one of those being analysed objectively (1988). Each trace was assessed for the existence of strong inversions within the 250-600 m layer, and relevant details noted concerning the more significant. From an initial list of 115 events a reduced list was prepared which consisted of the 40 in that year which were considered to be most severe in terms of the 250-600 m layer. That list was subsequently compared with the list of inversions produced as part of the computer-generated climatology. Of the 40 events 32 were also identified by the objective test. A final list was therefore prepared which consisted of these 32 events. These events were examined in greater detail. The inversion in each of these events thus satisfied the following criteria: ground-based inversions were at least 250 m thick; all elevated inversions were at least 200 m thick; and the average temperature increase in all inversions was at least 1°C per 100 m. The results of this analysis are presented in Section 5.3.

5.2 Events Identified Objectively in 1987 to 1991

The inversions which satisfied the objective test outlined above are referred to in the following as "major". The numbers of days on which these "major" inversions occurred were tabulated. A supplementary table excluding those days when the only inversion identified was ground-based and between 200 m and 250 m thick was prepared also. These latter inversions might be excluded from consideration because they existed exclusively below the advised approximate minimum equilibrium plume level of 250 m. However, their inclusion in considerations would make some allowance for the tendency of the inversion top to rise as the inversion is eroded from below, by rising thermals overshooting their equilibrium level.

The frequencies of occurrence of such inversions are presented in Table 8. Over the year as a whole, they are typically recorded on about 30% of days, or about 110 days per year. On approximately 4% of days, or about 15 days per year, the only "major" inversion existed totally below 250 m. The occurrence of "major" inversions was most frequent in January, February and April, with about 40% of days affected, and least frequent in October when such inversions were recorded on approximately 18% of days. When the days were excluded on which the only "major" inversions existed entirely below 250 m these figures change slightly to about 39% in January-February and 15% in October. Looking at individual months, the inversions confined totally below 250 m occurred most frequently during the winter period. Again, this distribution through the year is in agreement with the climatological finding that the mean stability in the lowest 1000 m is greatest in the first half of the year.

The frequency of occurrence of such inversions in each of the five years examined varied slightly, from 100 in 1988 to 122 in 1987. The frequencies of events in individual months varied more between years.

In keeping with the findings of the analysis discussed in the previous Section, the "major" inversions during the winter months were almost exclusively ground-based.

"Major" low level inversions present at the time of the morning sonde in 1987 and 1988 have been analysed further. All the inversions were processed, including those ground-based ones which were 200-250 m thick. A total of 225 were identified in the two-year period. There were three days on which two separate inversions satisfied the specified criteria. In each case the lowest was surface-based and 200-250 m thick.

"Major" elevated inversions occurred particularly between November and March. Of the elevated inversions two-thirds had their base between 100 m and 400 m, the other third between 400 m and 600 m. Further details regarding the occurrence of "major" inversions in each month for the two-year period are presented in Table 9.

The temperature change and thickness of the 225 inversions were examined, with the data divided into three. These groups, and the number of events in each, were as follows:

- o base height 100 m or less, April to September:
  100 inversions (98 ground-based).
- o base height 100 m or less, October to March:
  38 inversions (32 ground-based).
- o base height 101-600 m, all months combined:
  87 inversions.

These analyses are presented in Table 10.

Although present in the soundings less frequently in the warmer months, those surface-based inversions which are present are frequently thick: 12 of the 38 were at least 500 m thick. This compares with only 3 in the 100 during the winter period. Ground-based inversions throughout the year occasionally have temperature increases in excess of 10°C through them. Some of these are also thick. Likewise, some of the elevated inversions exceeded 500 m in thickness, and temperature changes greater than 10°C were again evident. The more extreme events in the whole of the five-year period are investigated further in Section 5.4 below.

5.3 Major Events Identified Visually in 1988 Data

For each of the 32 dates identified visually in the 1988 data as having high significance the following fields were extracted, where possible:

- o The base of the inversion (m).
- o The thickness of the inversion (m).
- o The temperature change through the inversion (°C).
- o The lapse rate of temperature in the inversion (°C km^{-1}).
- o The 300 m wind direction (°) and speed (m s^{-1}).
- o The 600 m wind direction (°) and speed (m s^{-1}).
- o The estimated time for the mixing depth to extend to beyond 250 m, if applicable (WST).
- o The estimated time for the mixing depth to extend to beyond 600 m, if applicable (WST).
- o The approximate time the inversion base was present between 250 m and 600 m (hr).

Details concerning each of the 32 events are presented in Table 11. All of these events were also included in those analysed in Tables 8-10 and discussed previously in Section 5.2.

a. Winds

It should be noted that the 300 m and 600 m winds referred to are the mean vector winds throughout layers approximately 300 m thick, the first extending from the ground to an approximate height of 300 m, the second from 300 m to 600 m. They are not actual winds at specific heights.

For the 30 of the key occasions for which wind data were available, frequency distributions were constructed separately of the observations at each level. The data at each level were examined both for the year as a whole and separated into winter (April to September) and summer (October to March). These distributions are presented in Tables 12 and 13.

Of the 300 m winds, 19 events occurred with winds between northeast and east. Only one showed a westerly profile. The remaining cases were between north-northwest and south-southeast. Wind speeds were between 7.5 m s^{-1} and 12.5 m s^{-1} on half the occasions. A general easterly pattern was dominant in the summer cases. This reflects the preferred summertime synoptic pattern of a high pressure system located in Bight waters with a trough, on average, near the west coast. Winds between northeast and east dominated at 600 m also. Wind speeds at the higher level tended to be slightly stronger. No wind speeds below 2.5 m s^{-1} were recorded in the 30 cases.

There were few wintertime cases in 1988. The associated wind directions at both levels were fairly widely distributed, although there was a tendency for a concentration around northeast, particularly at 300 m. In order to increase the wintertime data sample significant cases from May and June 1989 were extracted from the computer generated output of "major" events. Some of these additional events were excluded as they were considered to be of lesser significance, for example, because the inversion was ground-based and less than 250 m thick. Of the 30 events listed in these two months 22 were considered. Details regarding these events are provided in Table 14. The corresponding wind distributions are presented in Tables 15 and 16.

In these additional events the winds at 300 m were almost exclusively from between north-northwest and east. Similarly, at 600 m wind directions were grouped between north-northwest and southeast.

In general, on individual occasions there was close agreement between the 300 m and 600 m winds.

The strongest speeds recorded at the two levels were 16 m s^{-1} at 300 m and 19 m s^{-1} at 600 m. Both were associated with tight east to northeast pressure gradients over the Perth area.

b. Estimating the Possible Occurrence of Conditions of Concern

For each of the 32 events estimates were made of the likely duration of mixing depths between 250 m and 600 m, because of their importance regarding fumigation and trapping of an elevated plume and therefore the possibility of high ground level concentrations of pollutants. Half-hour temperature data from Perth Airport were used in conjunction with the morning temperature sounding to estimate the development of a mixed layer through the day.

It was assumed that as the lower atmosphere heated the depth of a surface-based mixed layer increased, gradually eroding the base of any temperature inversion. The lapse rate of the mixed air was assumed to be dry adiabatic (temperature decreasing at approximately 1°C per 100 m). Using the morning sonde trace the surface temperature required for the mixed layer to reach 250 m in depth was calculated, as was the temperature needed to produce a mixed layer about 600 m deep. Particular note was made of the times when the mixed layer reached each of these depths. It was assumed in all calculations that the morning sonde trace remained representative of conditions above the mixed layer throughout the day.

In cases where the inversion was based above 250 m at sonde time it was not possible to ascertain when the mixing depth first reached that height. This happened on several occasions during summer. In such cases it was necessary to use the radiosonde flight time, 0600 WST, as a starting point and calculate when the mixed layer reached 600 m. Hence, in these events times when the inversion was between 250 m and 600 m are stated as "greater than x" hours, where "x" is the number of hours from flight time to when the estimated mixing depth exceeded 600 m. Similarly, in three cases the inversion was still present by the time of the evening radiosonde flight at 1800 WST. No reliable assumptions can be made regarding the likely evolution of the boundary layer after that time, particularly in relation to development of surface stability overnight. Consequently, on these occasions the time when the inversion was between 250 m and 600 m is again necessarily stated as "greater than x".

The time during which the mixing depth was estimated to be between 250 m and 600 m varied considerably between events. Mostly those conditions lasted 3 hr or less. Occasional periods of 4 hr or more occurred during the cooler months. During 1988 four occasions were identified when it appeared that such conditions would have lasted for over 8 hr. All occurred between October and February (Tables 11, 14).

To gain a further understanding of the processes involved two summer cases and one winter case were investigated in greater detail.

c. Examination of Specific Events

Summer Case 1 - 30 October 1988

Base of inversion: 282 m

Thickness of inversion: 307 m

Temperature change over inversion depth: 9.2°C

Lapse rate exhibited in inversion: 30.0°C km^{-1}

300 m wind (0600 WST): 090°/12 m s^{-1}

600 m wind (0600 WST): 050°/14 m s^{-1}

300 m wind (1200 WST): 025°/07 m s^{-1}

600 m wind (1200 WST): 015°/10 m s^{-1}

Time mixing depth exceeded 250 m: >250 m prior to 0600 WST

Time mixing depth exceeded 600 m: 1400 WST

Approximate time with inversion base 250-600 m: >8 hr

In the days preceding the event a narrow ridge extended along the south coast of WA from a high pressure system to the west of the state. Subsequently, a high pressure system became established near Esperance. Fine relatively cloud-free conditions with good overnight radiational cooling were present. A series of cold fronts were located well to the south, in a zone of vigorous westerly flow. To the north a broad trough extended from the Pilbara along the west coast.

The high pressure system near Esperance maintained intensity and moved gradually east to be centred near Ceduna on the morning of October 30. The mean sea level pressure analysis for that morning is shown in Figure 1a. The trough along the west coast deepened markedly. As a result a fresh northeast air stream existed over the Perth region. Fine, mainly cloud-free conditions continued.

By 0600 WST an elevated inversion existed and the mixing depth exceeded 250 m. As was mentioned above, it was not possible to determine with any confidence how long the mixing depth had exceeded 250 m before 0600 WST. For the depth of mixing to exceed 600 m the surface temperature needed to reach 21°C or more. This temperature was reached at around 1400 WST.

The 300 m and 600 m winds at 0600 WST were easterly to northeasterly of 12 m s^{-1} and 14 m s^{-1} respectively. By 1200 WST the winds at both levels had backed to around north-northeast and had eased.

No significant inversion was apparent on the sonde flight on the evening of October 30 1988.

Over following days the high pressure system continued a steady eastward progression. A deep southern ocean low pressure system and associated cold front to the southwest of WA moved rapidly toward the state, and passed through the southern half during October 31 and November 1.

Summer Case 2 - 5 January 1988

Base of inversion: 0 m

Thickness of inversion: 547 m

Temperature change over inversion depth: 8.8°C

Lapse rate exhibited in inversion: 16.1°C km-1

300 m wind (0600 WST): 350°/04 m s^{-1}

600 m wind (0600 WST): 310°/04 m s^{-1}

300 m wind (1200 WST): 275°/06 m s^{-1}

600 m wind (1200 WST): 275°/06 m s^{-1}

300 m wind (1800 WST): 255°/05 m s^{-1}

600 m wind (1800 WST): 235°/08 m s^{-1}

Time mixing depth exceeded 250 m: 0700 WST

Time mixing depth exceeded 600 m: mixing depth had not exceeded 600 m by the time of the evening sounding, 1800 WST

Approximate time with inversion base 250-600 m: >11 hr

In the days preceding this major inversion event a high to the west of the state extended a ridge along latitude 35°S. A moderate high pressure centre became established in the eastern Bight, and in combination with a rapidly deepening trough along the west coast produced a fresh to strong northeast wind flow over the southwest of WA. Observations indicate that conditions were fine with little significant cloud.

On the morning of 5 January 1988 the high pressure system which had become established in the Bight had moved further east. The trough extended from the northwest of the state along the west coast and off the coast near Albany. A weak low pressure centre was analysed in the trough just to the south of Perth (Figure 1b). The winds at Perth Airport at 300 m and 600 m at 0600 WST reflected this situation: light north to northwest winds occurred at both levels.

The morning sonde trace revealed the presence of a surface-based inversion, but a mixed layer extended to above 250 m by about 0700 WST. For the depth of mixing to exceed 600 m the surface temperature needed to reach approximately 30.5°C. This temperature was never reached. By 1200 WST westerly winds had become established. By 1800 WST the upper winds had shifted to the west-southwest. These changes appear to have been associated with a movement of the trough slightly east. There may have been a contribution from a sea breeze also. The temperature sounding at 1800 WST showed that significant cooling attributable to a change of air mass had occurred from the surface to beyond 2000 m and a strong inversion was still present at about 500 m. It appears, therefore, that the mixed depth remained below 600 m from around 0700 WST to at least 1800 WST. It is not possible to determine the behaviour of the mixed layer after that time.

Over the next two days the trough near the west coast moved east. A marked cold front approached the southwest of WA, moving through the lower west and weakening during that period.

Winter Case - 31 July 1988

Base of inversion: 0 m
Thickness of inversion: 524 m
Temperature change over inversion depth: 6.0°C
Lapse rate exhibited in inversion: 11.5°C km^{-1}
300 m wind (0600 WST): 050°/10 m s^{-1}
600 m wind (0600 WST): 025°/14 m s^{-1}
300 m wind (1200 WST): 010°/03 m s^{-1}
600 m wind (1200 WST): 320°/04 m s^{-1}
Time mixing depth exceeded 250 m: 0900 WST
Time mixing depth exceeded 600 m: 1330 WST
Approximate time with inversion base 250-600 m: 4.5 hr

During 29 and 30 July a high pressure system became established in the Bight near 130°E. A broad trough was present along the west coast. The pressure gradient which resulted over the southwest of the state produced a moderate northeast air stream. Clear conditions provided good radiational cooling overnight on 30-31 July.

The high pressure system in the Bight moved northeast and by 31 July was centred in southern central SA with a ridge extending back into WA (Figure 1c). Consequently the lower southwest of the state remained in a northeast wind pattern as exhibited by the 300 m and 600 m winds at 0700 WST. By 1300 WST the winds were light and from the north to northwest.

The temperature inversion was ground-based initially, and a temperature of 14°C was necessary before the mixing depth reached the critical height of 250 m. This temperature was reached at about 0900 WST. Further surface heating saw the depth of mixed layer reach 600 m when the temperature exceeded 21°C. This occurred at about 1330 WST. Among the events examined in detail this was a major wintertime inversion: the critical period during other significant winter events typically was shorter.

A major cold front which was approaching the state from the southwest on 31 July moved through the southern half of the state the following day.

5.4 The Occurrence of Inversion Events Comparable With That Modelled by CSIRO

A temperature sounding carried out at Bunbury early on the morning of 28 April 1982 has been used previously by Westralian Sands Limited to provide an indication of the most extreme meteorological conditions to be expected. The sounding has been used in numerical modelling studies of the possible impact of the proposed operation at Capel. The predawn sounding on 28 April shows an inversion approximately 400 m deep through which the temperature increased by a total of approximately 10.1°C. Nearly 6°C of that total increase occurred in the lowest 80 m or so. Such an inversion clearly satisfies the three criteria used to define "major" inversions in Section 5.1.

The listing of "major" low level inversions produced as part of the computer-generated climatology has been examined to identify the occurrence of any inversions with comparable features.

This examination identified 16 occasions within the five-year period analysed of ground-based inversions which were at least 300 m thick and through which the temperature increased by at least 10°C. In a further 11 cases the inversion was of similar thickness and the temperature increase was between 9°C and 10°C. There were seven other inversions identified which were elevated, their bases at least 200 m above ground, all of which were over 300 m thick and through which the temperature increased by at least 9°C. In three of those inversions the temperature increase was more than 10°C.

All of these inversions might be considered to be comparable in severity to that of 28 April 1982. Details regarding each of these events is presented in Table 17.

The ground-based inversions occurred in most months, although there was some increased tendency for occurrence between January and June. Wind data were examined for 19 of the 27 events with ground-based inversions. About half were associated with north to northeast winds, one third with east to southeast winds and one fifth with winds from the south-southeast. In 14 of the 19 cases the directions at 300 m and 600 m differed by less than 45°. On 17 occasions the wind speed at the lower level was 7 m s^{-1} or less. The strongest winds were from the north to northeast. Most events had only small changes in wind direction between the early morning and midday soundings.

The elevated inversions all occurred between October and February. Of the four events for which wind data were readily available, all showed easterly winds. Wind directions at 0600 WST again showed little change with height. The directions had also changed little by midday in three of the events; a sea breeze was apparent in the fourth.

5.5 *Synoptic Pressure Patterns Characteristic of Major Temperature Inversion Events*
An examination of the synoptic pressure patterns at the times of significant inversions indicated that certain synoptic situations appeared regularly. These most prominent patterns reflect the high frequency of winds between east and north observed at the times of these events. Three such patterns are described briefly.

Synoptic Situation 1

A major high pressure system located in the eastern Bight is gradually moving east. This high extends a ridge westward. A low pressure trough may extend down the west coast, typically slightly offshore. Northeast winds result over the lower west of the state. This pattern is common in summer.

The continental origin of the air reaching the lower west generally results in relatively cloud-free skies and good overnight radiational cooling. It is probable that elevated inversions develop or are enhanced in areas near the lower west coast due to the hot continental air being undercut by cooler maritime air in the sea breeze.

Synoptic Situation 2

In this case the region is in a col, an area of weak pressure gradients and light winds between two high pressure systems. Once again clear skies are common and good radiational cooling can occur.

Synoptic Situation 3

In winter an anticyclone is centred over mainland Australia. A westerly trough may be located southwest of the area of interest.

These patterns all have many characteristics in common, and are in many ways variations on one more general pattern. The two key features of such a pattern are:

- an anticyclone centred broadly east or south of the region of interest. This system is the main influencing factor.
- a trough along or offshore from the west coast. The trough may in some instances be weak, sometimes no more than an area of lower pressures between two high pressure cells. Occasionally it may be absent altogether.

Depending on the strengths and locations of the various systems in individual cases the precise direction of air flow varies. In summer the ridge is generally along or to the south of the south coast, and northeast to east flow dominates, with occasional southeast flow. Such situations involve a significant overland trajectory of the air. The proximity to the high pressure ridge and the clear skies which frequently exist on such occasions are conducive to the occurrence of stable conditions in the lower atmosphere.

In winter the ridge is typically located further north, across southern and central Australia. The associated wind directions in the Perth-Bunbury area are more likely to be northeast to north. Northwest winds may also be of some importance. In winter such winds may approach the lower west coast from tropical ocean regions, passing initially over cooler waters and then over the cooled land mass. Such circumstances are conducive to the stabilisation of the atmosphere near the ground, especially if the winds are fairly light and skies clear, as is frequently the case on the rear of a continental anticyclone.

In summer, the main low pressure trough is likely to be extending down the west coast from the subtropics. A weak high latitude westerly trough may also be apparent further south. By comparison, in winter the reverse situation is more likely with the major trough being in the westerly air stream over higher latitudes. On the occasions of interest here this trough is likely to be either weak or well to the west of the WA coast.

Examples of mean sea level pressure analyses for the three cases examined in Section 5.3 are presented in Figure 1. Other typical analyses are shown in Figure 2 for summer events and in Figure 3 for winter events.

An analysis of one occasion associated with a westerly wind is presented in Figure 4. This situation appears to have resulted following passage of a very weak front which barely affected the south coast. The pressure gradient was light over the Perth-Bunbury area and skies were fairly clear overnight. The near-ground air apparently stabilised in these conditions, possibly assisted by the approach of a new anticyclone from the west. Fog was reported at Perth Airport around sunrise.

Table 1: The lengths of the various data records (years) used to describe climatological conditions in the Bunbury area.

Variable	Perth Airport	Bunbury	Albany
Surface wind	47	21	-
Surface temperature	42	20	-
Upper air data	19	-	11

Table 2: The climatological frequencies of occurrence (percentages, rounded to the nearest whole number) of winds in three speed ranges at Bunbury Post Office and at Perth Airport. The three ranges are:

A - less than 3.0 m s^{-1}

B - 3.0 - 8.4 m s^{-1}

C - 8.5 m s^{-1} or more

a. 0900 WST

Month	Bunbury Post Office			Perth Airport		
	A	B	C	A	B	C
January	55	38	8	27	66	7
February	48	44	8	29	61	10
March	54	41	6	35	57	7
April	64	29	5	48	46	5
May	68	24	9	58	39	4
June	61	24	15	57	42	2
July	63	26	12	57	37	5
August	62	29	9	54	41	3
September	62	32	6	49	46	5
October	57	34	9	40	55	6
November	59	34	8	30	63	7
December	59	36	5	30	64	6

Table 2 (continued):

b. 1500 WST

Month	Bunbury Post Office			Perth Airport		
	A	B	C	A	B	C
January	43	51	6	11	80	8
February	46	47	7	15	77	8
March	50	45	4	19	77	5
April	50	42	8	28	67	5
May	51	40	9	36	58	6
June	47	37	16	34	59	6
July	44	40	15	33	59	7
August	45	41	13	30	62	9
September	46	46	7	22	70	7
October	45	47	8	12	79	9
November	46	45	8	9	81	9
December	47	47	6	8	82	10

Table 3: Features of the average low level atmospheric stability, Perth and Bunbury areas (900 hPa temperature estimated for Bunbury).

a. January

Variable	Perth Airport	Bunbury
Av. Minimum Temperature (^{o}C)	16.7	16.4
Av. Surface Temperature, 0900 WST (^{o}C)	23.7	22.0
Av. Surface Temperature, Sonde Release Time (^{o}C)	20.0	-
Av. Temperature, 900 hPa (^{o}C)	18.0	15.5
Av. Vertical Rate of Temperature Change, Sonde Time (^{o}C km^{-1})	-2.0	-

b. July

Variable	Perth Airport	Bunbury
Av. Minimum Temperature (^{o}C)	8.0	9.0
Av. Surface Temperature, 0900 WST (^{o}C)	11.5	12.0
Av. Surface Temperature, Sonde Release Time (^{o}C)	9.7	-
Av. Temperature, 900 hPa (^{o}C)	6.6	6.1
Av. Vertical Rate of Temperature Change, Sonde Time (^{o}C km^{-1})	-3.0	-

Table 4: The climatological frequencies of occurrence (%) of winds at around 500 m altitude in four speed ranges at Perth Airport.

a. 0600/0700 WST

Month	Wind 0-3	Speed 4-6	Range 7-10	($m\ s^{-1}$) >10	Total No. of Obs'ns
January	4.5	14.3	29.7	51.4	552
February	5.6	14.0	27.0	53.3	478
March	5.4	16.1	31.9	46.6	554
April	8.7	20.0	30.1	41.2	531
May	12.5	17.9	28.6	40.9	535
June	9.8	15.7	28.5	46.1	523
July	9.3	19.1	31.8	39.9	551
August	13.6	17.9	29.3	39.1	552
September	10.4	21.7	31.4	36.5	529
October	9.5	19.3	33.5	37.7	555
November	6.9	20.0	31.7	41.5	540
December	7.2	15.0	35.9	41.8	552
All Months	8.6	17.6	30.8	42.9	6452

Table 4 (continued):

b. 1200/1300 WST

Month	Wind 0-3	Speed 4-6	Range 7-10	($m\ s^{-1}$) >10	Total No. of Obs'ns
January	16.8	44.9	33.2	5.2	555
February	19.8	38.8	33.8	7.5	479
March	20.8	42.9	31.5	4.9	553
April	23.3	38.8	29.5	8.4	536
May	22.6	33.0	28.3	16.1	552
June	18.0	28.9	29.5	23.6	533
July	16.6	28.3	31.0	24.0	554
August	20.8	30.4	28.6	20.1	552
September	22.8	31.3	29.7	16.2	536
October	22.2	33.3	31.1	13.4	553
November	19.1	35.7	33.5	11.7	540
December	25.0	39.0	30.5	5.6	557
All Months	20.7	35.4	30.8	13.1	6500

Table 5: The climatological distribution of wind directions at around 500 m altitude for winds of 3 m s^{-1} or less at Perth Airport. Figures are the frequencies of occurrence (%), as fractions of the whole data record, of such winds in the direction ranges and for the periods specified.

a. 0600/0700 WST

Dir'n Range	Month Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	All
Calm	0.0	0.2	0.0	0.2	0.6	0.2	0.0	0.5	0.0	0.2	0.0	0.0	0.2
020-040	0.4	0.0	0.0	0.9	1.1	1.3	1.5	0.7	0.6	0.5	0.2	0.5	0.7
050-070	0.4	0.4	0.2	1.1	1.1	1.1	1.1	0.4	0.8	0.2	0.2	0.4	0.6
080-100	0.4	0.6	0.5	0.6	0.9	0.8	1.1	0.7	0.6	1.3	0.9	0.4	0.7
110-130	0.4	1.0	0.9	1.1	1.3	1.5	1.5	1.3	1.7	0.7	0.7	0.2	1.0
140-160	0.2	0.6	0.4	0.3	1.1	1.0	1.1	1.3	1.1	2.0	0.6	1.4	0.9
170-190	0.9	0.6	0.7	1.5	0.6	0.4	0.4	2.0	0.9	1.6	1.7	0.7	1.0
200-220	0.4	0.6	0.7	0.4	1.3	0.4	0.2	1.1	0.8	0.5	0.9	0.7	0.7
230-250	0.2	0.4	0.5	0.6	0.9	0.6	0.5	0.9	0.9	0.9	0.6	1.3	0.7
260-280	0.2	0.4	0.4	0.0	0.6	0.4	0.7	0.7	0.8	0.4	0.4	0.4	0.4
290-310	0.4	0.2	0.0	1.1	0.9	0.6	0.4	1.6	0.4	1.1	0.2	0.5	0.6
320-340	0.2	0.2	0.5	0.4	1.1	1.0	0.4	1.8	0.9	0.2	0.0	0.4	0.6
350-010	0.7	0.2	0.5	0.4	0.9	0.6	0.5	0.5	1.1	0.0	0.6	0.4	0.5
All	4.5	5.6	5.4	8.7	12.5	9.8	9.3	13.6	10.4	9.5	6.9	7.2	8.6

Table 5 (continued):

b. 1200/1300 WST

Dir'n Range	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	All
Calm	0.2	0.4	0.4	0.4	0.0	0.2	0.2	2.2	0.9	0.2	0.2	0.5	0.5
020-040	0.7	1.0	1.4	1.5	2.7	1.7	2.2	1.6	0.4	1.6	1.1	1.3	1.5
050-070	2.3	2.9	1.3	1.1	1.6	1.5	1.8	1.4	1.7	1.1	2.0	2.0	1.7
080-100	1.8	1.7	2.5	2.4	1.3	2.1	1.8	0.7	2.2	2.2	0.7	2.9	1.9
110-130	2.0	3.3	2.4	2.6	0.7	2.3	1.3	1.8	2.6	2.2	1.9	3.8	2.2
140-160	1.8	2.1	2.4	1.3	2.7	1.5	0.4	0.5	2.6	1.6	2.2	2.9	1.8
170-190	2.0	1.0	2.5	2.6	2.2	0.8	1.3	2.9	1.5	2.4	2.6	2.9	2.1
200-220	1.8	1.7	2.0	2.6	1.8	2.1	1.4	2.5	1.1	3.4	3.3	3.1	2.2
230-250	1.3	1.7	1.6	3.0	2.5	0.8	1.1	1.4	3.2	3.1	2.8	2.3	2.1
260-280	0.9	1.3	0.9	1.1	2.0	1.5	1.1	2.4	1.9	2.4	0.6	1.3	1.4
290-310	0.5	0.8	1.4	1.1	0.9	1.1	0.4	0.9	1.1	0.5	0.9	0.9	0.9
320-340	0.4	0.2	1.3	1.5	1.6	1.5	1.8	0.5	1.5	0.9	0.2	0.7	1.0
350-010	0.9	1.7	0.7	2.1	2.5	1.1	2.0	1.8	2.1	0.7	0.6	0.5	1.4
All	16.8	19.8	20.8	23.3	22.6	18.0	16.6	20.8	22.8	22.2	19.1	25.0	20.6

Table 6: Estimates of the frequency of occurrence of days on which at least one temperature inversion was present below 600 m. All figures are percentages.

A - Days with no inversion based below 2000 m

B - Days with a ground-based inversion

C - $\frac{\text{(No. of inversions based below 200 m)}}{\text{(Total no. of days)}}$

D - $\frac{\text{(No. of inversions with bases between 200 m and 600 m)}}{\text{(Total no. of days)}}$

Month	A	B	C	D	Est. no. of days with inversion below 600 m	
					Range	Best estimate
January	1.3	36.4	48.3	43.0	36-91	70-75
February	3.7	45.6	56.6	48.5	46-96	70-75
March	3.9	54.6	61.7	39.0	55-96	70-75
April	7.0	69.2	76.9	25.2	69-93	80-85
May	5.4	83.1	88.5	16.9	83-95	85-90
June	11.9	81.8	83.9	9.8	82-88	≈85
July	11.1	79.9	85.4	8.3	80-89	≈85
August	8.6	77.5	86.8	14.6	78-91	≈85
September	11.8	66.0	79.9	17.4	66-88	80-85
October	17.1	30.3	52.0	21.1	30-73	55-60
November	14.2	31.8	45.9	38.5	32-85	55-60
December	2.6	33.3	50.3	45.8	33-96	65-70
Annual	8.2	57.2	67.8	27.6	57-92	70-75

Table 7: The frequency of occurrence of recorded ground-based temperature inversions at least 400 m thick, 1987-1991. All figures are percentages.

A - Fraction of days having inversion 400-600 m thick

B - Fraction of days having inversion 600-800 m thick

C - Fraction of days having inversion >800 m thick

D - Fraction of days having inversion >400 m thick

E - Fraction of ground-based inversions >400 m thick

Month	A	B	C	D	E
January	7.3	2.7	0.0	9.9	27.3
February	13.2	2.9	0.0	16.2	35.5
March	10.4	5.2	0.7	16.3	29.8
April	11.9	4.2	0.7	16.8	24.2
May	11.5	0.0	0.0	11.5	13.8
June	2.8	0.7	0.0	3.5	4.3
July	6.9	0.0	0.7	7.6	9.6
August	10.6	0.7	0.0	11.3	14.5
September	6.3	1.4	0.0	7.6	11.6
October	4.0	0.7	0.0	4.6	15.2
November	1.4	1.4	0.0	2.7	8.5
December	3.3	0.7	0.7	4.6	13.7
Annual	7.4	1.7	0.2	9.3	16.3

Table 8: The number of days on which "major" temperature inversions, as defined in the text, were recorded. The figures in brackets give the number of days affected if days are excluded on which the only inversion so defined is ground-based and between 200 m and 250 m thick.

Month	1987	1988	Year 1989	1990	1991	Fraction of Days Monitored (%)
January	13(12)	14	11(10)	9	14	40.4(39.4)
February	10	12	8	8	15	39.0(39.0)
March	6(5)	7	10	9	10	27.3(26.6)
April	9(8)	7	6(5)	8(6)	10	28.0(25.2)
May	13(8)	7(6)	15(14)	13(9)	12(7)	40.5(29.7)
June	5(3)	8(6)	15(13)	17(14)	6(3)	35.7(27.3)
July	10(9)	8(7)	8(5)	10(6)	5(4)	28.5(21.5)
August	15(9)	5(2)	12(10)	5(3)	9(7)	30.5(20.5)
September	15	7(5)	7(5)	9(8)	10(8)	33.3(28.5)
October	5(4)	6	5(3)	3(2)	8	17.8(15.1)
November	11	11	7	11(10)	9(7)	33.1(31.1)
December	10	8	8	10(9)	10	30.1(29.4)
Annual	122 (104)	100 (91)	112 (98)	112 (93)	118 (103)	31.9 (27.7)

Table 9: The number of days on which "major" temperature inversions, as defined in the text, of various thicknesses were recorded in morning soundings at Perth Airport in 1987 and 1988 combined.

Month	Base Height (m)							Total
	0	1 - 100	101 - 200	201 - 300	301 - 400	401 - 500	501 - 600	
January	9	1	1	3	4	4	5	27
February	5		6	3	3	3	3	23
March	7			2	1	2	1	13
April	14		2					16
May	20							20
June	13							13
July	18							18
August	18		1			1		20
September	15	2	1		2	2	1	23
October	7	2		1		1		11
November	2	2	5	5	6	1	2	23
December	2	1	2	5	5	2	1	18
Annual	130	8	18	19	21	16	13	225

Table 10: The frequency of occurrence of various combinations of thickness and temperature change for "major" temperature inversions, as defined in the text, recorded in morning soundings at Perth Airport in 1987 and 1988 combined.

a. Base height less than 100 m, April to September inclusive.

Temperature Change (^{o}C)	Thickness (m) 200 - 299	300 - 399	400 - 499	500 - 599	600 - 699	700 - 799	800 - 899	Total
2.0-2.9	4							4
3.0-3.9	11	4						15
4.0-4.9	13	7	2					22
5.0-5.9	13	4	5					22
6.0-6.9	5	4	2	1	1			13
7.0-7.9	2	6	3					11
8.0-8.9	1	2	1					4
9.0-9.9	2	2	1					5
10.0-10.9						1		1
11.0-11.9		1	2					3
12.0-12.9								
Total	51	30	16	1	1	1		100

Table 10 (continued):

b. Base height less than 100 m, October to March inclusive.

Temperature Change (°C)	Thickness (m) 200 - 299	300 - 399	400 - 499	500 - 599	600 - 699	700 - 799	800 - 899	Total
2.0-2.9	1							1
3.0-3.9	5							5
4.0-4.9	1	3	1					5
5.0-5.9				1				1
6.0-6.9	1	3	1	2	1			8
7.0-7.9			4	3				7
8.0-8.9			4	1	2			7
9.0-9.9						1		1
10.0-10.9		1			1			2
11.0-11.9		1						1
12.0-12.9								
Total	8	8	10	7	4	1		38

Table 10 (continued):

c. Base height 100 m or greater, all months.

Temperature Change (°C)	Thickness (m) 200 - 299	300 - 399	400 - 499	500 - 599	600 - 699	700 - 799	800 - 899	Total
2.0-2.9	2							2
3.0-3.9	16	2						18
4.0-4.9	7	6	2					15
5.0-5.9	6	7	2					15
6.0-6.9	5	2	5	1	1			14
7.0-7.9	2	3	3	1				9
8.0-8.9	3	2	3					8
9.0-9.9		2	1					3
10.0-10.9		1	1					2
11.0-11.9				1				1
12.0-12.9								
Total	41	25	17	3	1			87

Table 11: Details concerning 32 occasions on which "major" temperature inversions were recorded in morning soundings at Perth Airport during 1988.

Date	Inversion Base(m)	Inversion Thickness(m)	Inversion Temp Change (C)	Lapse Rate (C/km)	300m Wind Dir/Spd(m/s)	600m Wind Dir/Spd(m/s)	Estimated Erosion Time to 600m (WST)	Approx Time Base 250m to 600m(hr)
Jan 88								
5	0	547	8.8	16.1	350/04	310/04	Present 1800	>11
17	405	439	10.6	24.1	125/06	130/07	0830	2.5
Feb 88								
10	475	570	11.2	19.7	085/09	100/16	0700	>1
11	312	282	8.2	29.1	095/15	060/13	1000	>4
12	288	319	6.6	20.7	080/10	070/13	0945	>3.75
13	273	212	3.6	17	075/13	055/19	0915	>3.25
16	146	358	5.8	16.2	080/09	065/11	0930	2
17	181	204	4.4	21.6	080/14	050/14	0930	>3.5
19	137	309	5.6	18.1	060/16	050/14	1045	3
21	0	410	8	19.5	050/11	030/10	0945	1.75
22	0	558	7.2	12.9	070/10	040/05	Present 1800	>8.5
Mar 88								
17	0	470	8.8	18.7	025/10	025/12	1015	2
18	0	482	7.8	16.2	060/07	045/07	1030	2
19	0	302	6	19.9	060/08	030/10	1030	2
20	208	476	7.2	15.1	080/10	035/14	1115	3
Apr 88								
23	0	294	7.6	25.9	045/02	240/03	1030	1.25
24	0	296	6.2	21	280/03	245/11	1130	1.25
May 88								
7	0	288	5.2	18.1	060/10	020/06	1000	0.75
8	0	415	9.4	22.6	135/02	120/06	1045	1.25
29	0	305	8	26.3	025/08	350/08	1115	1.25
Jun 88								
22	0	626	6.8	10.9	N/A	N/A	1200	3.25
30	0	355	6	16.9	N/A	N/A	1500	5
Jul 88								
1	0	397	5	12.6	065/12	065/11	1215	3.5
27	0	397	7.2	18.1	020/10	350/10	1115	1
31	0	524	6	11.5	050/10	025/14	1330	4.5
Aug 88								
22	0	340	7.6	22.4	360/11	350/07	1100	1.75
Sep 88								
3	0	376	6.2	16.5	160/04	135/03	1030	1
Oct 88								
24	0	440	7.8	17.7	050/05	030/12	1100	2.5
30	282	307	9.2	30	090/12	050/14	1400	>8
Nov 88								
10	101	607	6.6	10.9	070/16	045/17	0945	2.75
Dec 88								
12	50	419	8.8	21	120/02	065/07	0945	2.5
13	0	392	11.2	28.5	130/03	170/04	Present 1800	>10.5

Table 12: Frequency distributions of wind speed and direction, 300 m level, for 30 occasions on which "major" temperature inversions were recorded in morning soundings at Perth Airport in 1988.

a. All months combined.

SIGNIFICANT CASES 1988. 300M WIND. ALL YEAR.

Speed m/s	0-2.4	2.5-4.9	5-7.4	7.5-9.9	10-12.4	12.5-14.9	15-17.4	17.5-19.9	20-22.4
Direction									
005,010									
015,020					1				
025,030				1	1				
035,040									
045,050	1		1		2				
055,060			1	1	1		1		
065,070					2		1		
075,080				1	2	2			
085,090				1	1				
095,100							1		
105,110									
115,120	1								
125,130		1	1						
135,140	1								
145,150									
155,160		1							
165,170									
175,180									
185,190									
195,200									
205,210									
215,220									
225,230									
235,240									
245,250									
255,260									
265,270									
275,280		1							
285,290									
295,300									
305,310									
315,320									
325,330									
335,340									
345,350		1							
355,360					1				

Table 12 (continued):

b. April to September.

SIGNIFICANT CASES 1988. 300M WIND. APRIL TO SEPTEMBER.

Speed m/s	0-2.4	2.5-4.9	5-7.4	7.5-9.9	10-12.4	12.5-14.9	15-17.4	17.5-19.9	20-22.4
Direction									
005,010									
015,020					1				
025,030				1					
035,040									
045,050	1				1				
055,060					1				
065,070					1				
075,080									
085,090									
095,100									
105,110									
115,120									
125,130									
135,140	1								
145,150									
155,160		1							
165,170									
175,180									
185,190									
195,200									
205,210									
215,220									
225,230									
235,240									
245,250									
255,260									
265,270									
275,280		1							
285,290									
295,300									
305,310									
315,320									
325,330									
335,340									
345,350									
355,360					1				

Table 12 (continued):

c. October to March.

SIGNIFICANT CASES 1988, 300M WIND, OCTOBER TO MARCH.

Speed m/s	0-2.4	2.5-4.9	5-7.4	7.5-9.9	10-12.4	12.5-14.9	15-17.4	17.5-19.9	20-22.4
Direction									
005,010									
015,020									
025,030					1				
035,040									
045,050			1		1				
055,060			1	1			1		
065,070					1		1		
075,080				1	2	2			
085,090				1	1				
095,100							1		
105,110									
115,120	1								
125,130		1	1						
135,140									
145,150									
155,160									
165,170									
175,180									
185,190									
195,200									
205,210									
215,220									
225,230									
235,240									
245,250									
255,260									
265,270									
275,280									
285,290									
295,300									
305,310									
315,320									
325,330									
335,340									
345,350		1							
355,360									

Table 13: Frequency distributions of wind speed and direction, 600 m level, for 30 occasions on which "major" temperature inversions were recorded in morning soundings at Perth Airport in 1988.

a. All months combined.

SIGNIFICANT CASES 1988. 600M WIND ALL YEAR.

Speed m/s	0-2.4	2.5-4.9	5-7.4	7.5-9.9	10-12.4	12.5-14.9	15-17.4	17.5-19.9	20-22.4
Direction									
005,010									
015,020			1						
025,030					4	1			
035,040			1			1			
045,050			1			3	1		
055,060						1		1	
065,070			1		2	1			
075,080									
085,090									
095,100							1		
105,110									
115,120			1						
125,130			1						
135,140		1							
145,150									
155,160									
165,170		1							
175,180									
185,190									
195,200									
205,210									
215,220									
225,230									
235,240		1							
245,250					1				
255,260									
265,270									
275,280									
285,290									
295,300									
305,310		1							
315,320									
325,330									
335,340									
345,350			1	1	1				
355,360									

Table 13 (continued):

b. April to September.

SIGNIFICANT CASES 1988, 600M WIND, APRIL TO SEPTEMBER.

Speed m/s	0-2.4	2.5-4.9	5-7.4	7.5-9.9	10-12.4	12.5-14.9	15-17.4	17.5-19.9	20-22.4
Direction									
005,010									
015,020			1						
025,030						1			
035,040									
045,050									
055,060									
065,070					1				
075,080									
085,090									
095,100									
105,110									
115,120			1						
125,130									
135,140		1							
145,150									
155,160									
165,170									
175,180									
185,190									
195,200									
205,210									
215,220									
225,230									
235,240		1							
245,250					1				
255,260									
265,270									
275,280									
285,290									
295,300									
305,310									
315,320									
325,330									
335,340									
345,350			1	1	1				
355,360									

Table 13 (continued):

c. October to March.

SIGNIFICANT CASES 1988. 600M WIND. OCTOBER TO MARCH.

Speed m/s	0-2.4	2.5-4.9	5-7.4	7.5-9.9	10-12.4	12.5-14.9	15-17.4	17.5-19.9	20-22.4
Direction									
005,010									
015,020									
025,030					4				
035,040			1			1			
045,050			1			3	1		
055,060						1		1	
065,070			1		1	1			
075,080									
085,090									
095,100							1		
105,110									
115,120									
125,130			1						
135,140									
145,150									
155,160									
165,170		1							
175,180									
185,190									
195,200									
205,210									
215,220									
225,230									
235,240									
245,250									
255,260									
265,270									
275,280									
285,290									
295,300									
305,310									
315,320		1							
325,330									
335,340									
345,350									
355,360									

Table 14: Details concerning 22 occasions on which "major" temperature inversions were recorded in morning soundings at Perth Airport during May and June 1989.

Date	Inversion Base(m)	Inversion Thickness(m)	Inversion Temp Change (C)	Lapse Rate (C/km)	300m Wind Dir/Spd(m/s)	600m Wind Dir/Spd(m/s)	Estimated Erosion Time to 600m (WST)	Approx Time Base 250m to 600m(hr)
May 89								
2	0	267	5.2	19.4	065/01	230/04	1045	1.25
3	0	285	4.4	15.4	100/07	140/05	1030	0.5
4	0	310	5.4	17.4	095/07	085/05	1000	1.5
5	403	227	3.2	14.1	090/12	070/13	1015	>4.5
6	0	379	3.8	10	060/09	060/13	1015	1.75
7	0	474	5	10.5	050/09	030/16	0945	1.5
8	0	329	7.4	22.5	035/09	030/10	1030	1.5
9	0	349	7.8	22.3	020/07	010/06	1215	1.75
10	0	425	9.4	22.1	190/04	200/03	1115	1.25
13	0	471	7	14.9	070/09	035/09	1145	3
25	0	306	3.4	11.1	060/12	060/12	1000	1
Jun 89								
3	0	362	5.6	15.5	065/05	085/02	1000	1.25
4	0	388	4.2	10.8	035/09	025/10	1030	1.25
5	0	381	8	21	345/09	345/14	1300	2.75
16	0	304	6	19.7	355/04	200/04	1130	2.5
19	0	370	4.2	11.3	060/09	045/15	1100	1.75
20	0	347	3.6	10.4	060/07	025/15	1030	1
21	0	371	5.2	14	035/08	010/07	1130	2.5
23	0	449	4.6	10.3	060/07	045/12	1130	2.25
24	0	304	5.6	18.4	020/12	035/12	1045	2.5
25	0	332	9.6	28.9	015/07	345/03	1200	2.75
27	0	403	6.6	16.4	015/12	020/15	1115	2

Table 15: Frequency distributions of wind speed and direction, 300 m level, for 22 occasions on which "major" temperature inversions were recorded in morning soundings at Perth Airport during May and June 1989.

SIGNIFICANT CASES MAY AND JUNE 1989, 300M WIND.

Speed m/s	0-2.4	2.5-4.9	5-7.4	7.5-9.9	10-12.4	12.5-14.9	15-17.4	17.5-19.9	20-22.4
Direction									
005,010									
015,020			2		2				
025,030									
035,040				3					
045,050				1					
055,060			2	2	1				
065,070	1		1	1					
075,080									
085,090					1				
095,100			2						
105,110									
115,120									
125,130									
135,140									
145,150									
155,160									
165,170									
175,180									
185,190		1							
195,200									
205,210									
215,220									
225,230									
235,240									
245,250									
255,260									
265,270									
275,280									
285,290									
295,300									
305,310									
315,320									
325,330									
335,340									
345,350				1					
355,360		1							

Table 16: Frequency distributions of wind speed and direction, 600 m level, for 22 occasions on which "major" temperature inversions were recorded in morning soundings at Perth Airport during May and June 1989.

SIGNIFICANT CASES MAY AND JUNE 1989, 600M WIND

Speed m/s	0-2.4	2.5-4.9	5-7.4	7.5-9.9	10-12.4	12.5-14.9	15-17.4	17.5-19.9	20-22.4
Direction									
005,010			2						
015,020							1		
025,030					2		2		
035,040				1	1				
045,050					1		1		
055,060					1	1			
065,070						1			
075,080									
085,090	1		1						
095,100									
105,110									
115,120									
125,130									
135,140			1						
145,150									
155,160									
165,170									
175,180									
185,190									
195,200		2							
205,210									
215,220									
225,230		1							
235,240									
245,250									
255,260									
265,270									
275,280									
285,290									
295,300									
305,310									
315,320									
325,330									
335,340									
345,350		1				1			
355,360									

Table 17: Details regarding the most severe low level temperature inversions recorded at Perth Airport in the five years, 1987 to 1991.

a. Ground-based inversions.

Date	Base Height (m)	Thickness (m)	Temperature Change (^{o}C)
04 Jan 1987	0	686	10.2
19 Aug 1987	0	458	11.6
16 Sep 1987	0	740	10.4
17 Sep 1987	0	332	11.2
02 Oct 1987	0	381	10.8
13 Dec 1988	0	392	11.2
02 Feb 1989	0	487	15.0
04 Feb 1989	0	437	10.0
22 Feb 1989	0	302	10.4
20 Mar 1989	0	582	10.2
22 Jun 1990	0	340	11.6
28 Jun 1990	0	284	10.2
31 Jan 1991	0	465	10.0
01 Feb 1991	0	595	14.6
05 Apr 1991	0	408	12.8
11 Dec 1991	0	533	11.0
08 May 1988	0	415	9.4
23 Jun 1988	0	395	9.4
30 Mar 1989	0	526	9.0
10 May 1989	0	425	9.4
25 Jun 1989	0	332	9.6
14 Sep 1989	0	655	9.6
07 May 1990	0	435	9.4
12 May 1990	0	473	9.0
06 Sep 1990	0	384	9.6
27 Mar 1991	0	391	9.8
17 Apr 1991	0	321	9.8

Table 17 (continued):

b. Elevated inversions.

Date	Base Height (m)	Thickness (m)	Temperature Change (^{o}C)
21 Dec 1987	398	332	10.6
17 Jan 1988	405	439	10.6
01 Mar 1991	215	536	10.2
13 Nov 1987	366	351	9.2
18 Dec 1987	224	471	9.0
30 Oct 1988	282	307	9.2
28 Feb 1991	485	365	9.6

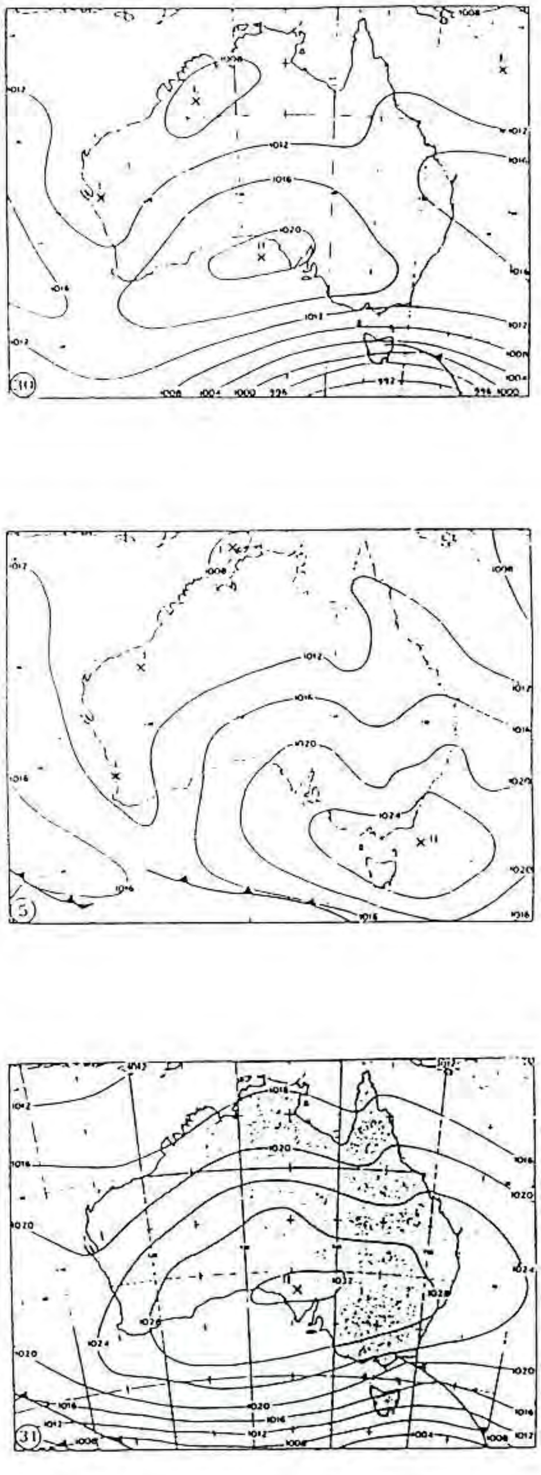

Figure 1: Mean sea level pressure analyses associated with case studies of major low level temperature inversions.

a. 30 October 1988.

b. 5 January 1988.

c. 31 July 1988.

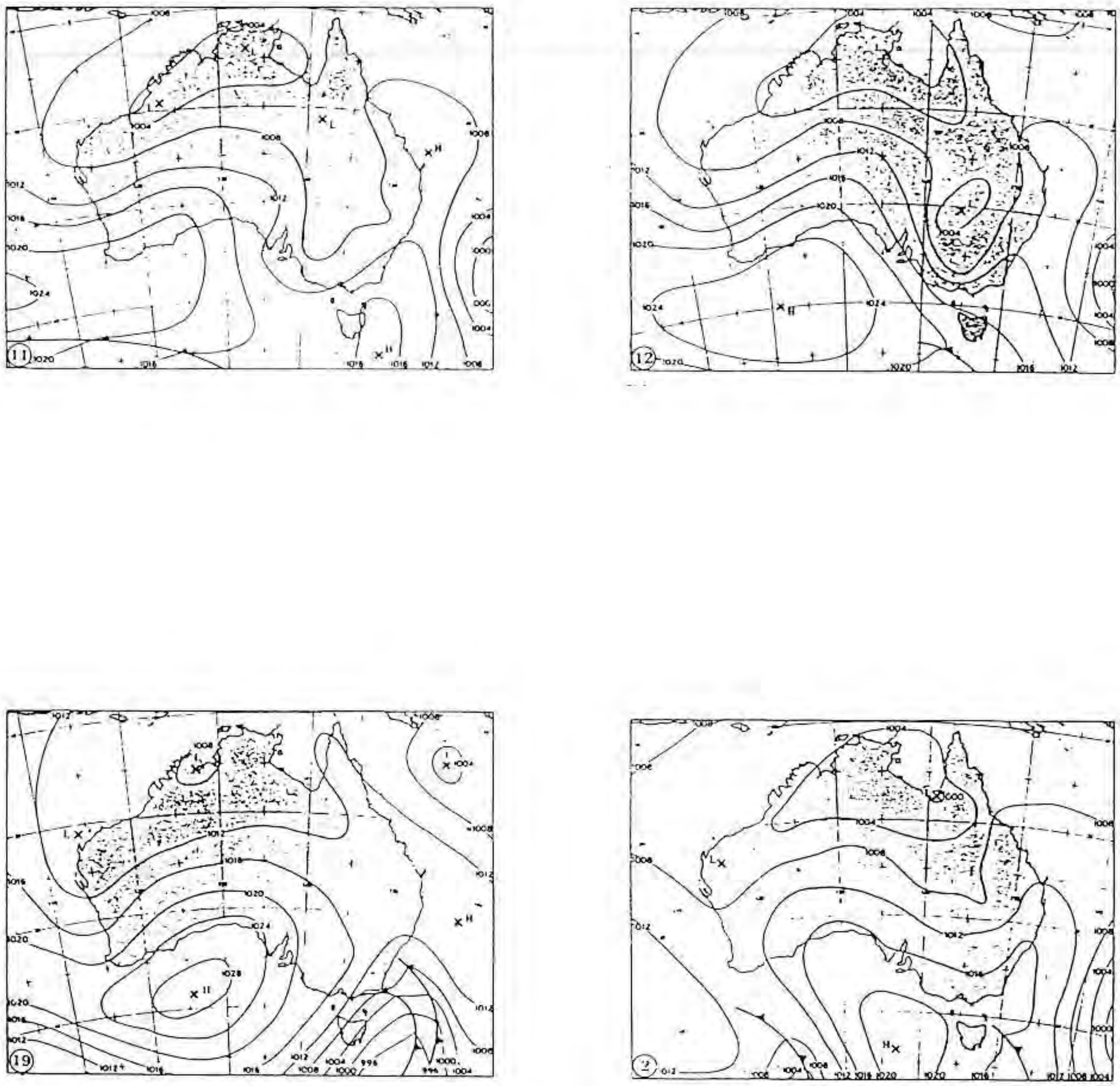

Figure 2: Typical mean sea level pressure analyses associated with major low level temperature inversion occurrence, summer events.

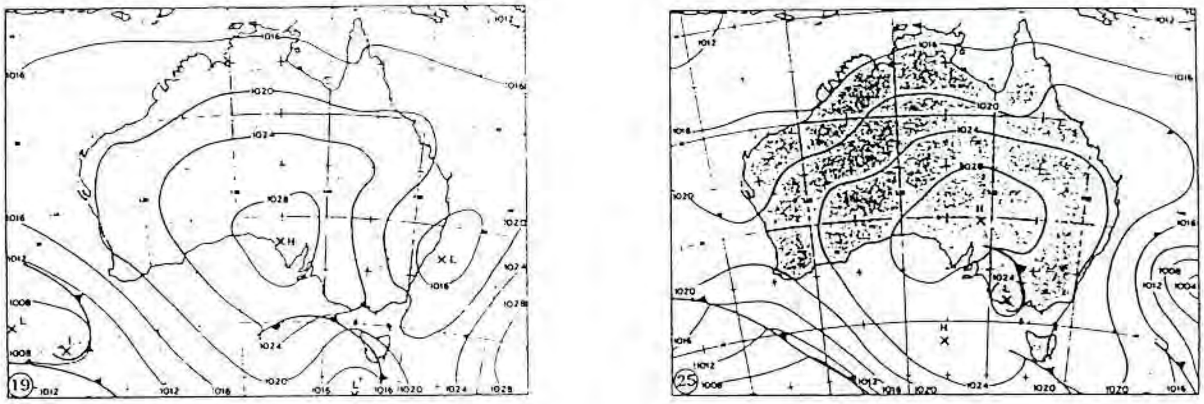

Figure 3: Typical mean sea level pressure analyses associated with major low level temperature inversion occurrence, winter events.

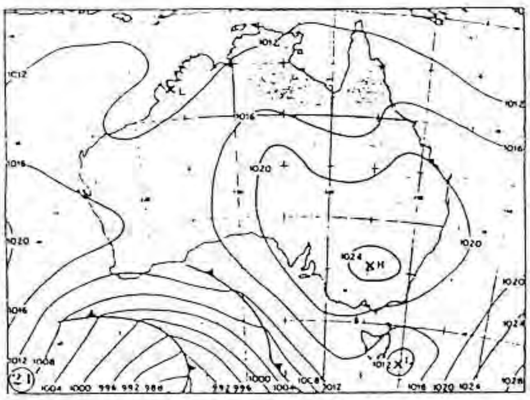

Figure 4: Mean sea level pressure analysis associated with a major low level temperature inversion in a westerly air stream, 28 April 1988.

APPENDIX 7

Westralian Sands Limited

Environmen Policy

Policy Objectives:

1. To comply with environmental laws and regulations relevant to the company's activities.
2. To go beyond the standards which are legally required.
3. To ensure due diligence by implementing proactive programs which include environmental matters as an integral part of all the company's operations.
4. To use the best, cost effective technology in order to minimise the impacts of all aspects of operations on the environment.
5. To regularly monitor environmental performance in order to assess, review and improve management practices.
6. To place a high priority on researching and developing improved environmental technology and to share with the community the benefits of that research.
7. To enhance the environmental awareness of all employees and to encourage sound environmental attitudes.
8. To place high priority on energy conservation, waste minimisation and recycling strategies.
9. To use the company's environmental resources and technology to support public education in areas of conservation, environment and land management.
10. To recognise the dynamic nature of environmental management and thus review policy as the need arises.

Westralian Sands Limited is committed to responsible corporate management which will involve balancing good stewardship in the protection of the natural environment with the need for sound economic performance.
All employees and contractors are expected to take responsibility for the company's environmental performance.

CHIEF EXECUTIVE

23/9/1991