WMC (Olympic Dam Corporation) Pty Ltd

OLYMPIC DAM EXPANSION PROJECT

ENVIRONMENTAL IMPACT STATEMENT

TECHNICAL APPENDICES

KINHILL

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APPENDIX H

TERRAIN

This appendix provides background on the regional and Project Area terrain (including the surface hydrology of the Project Area), and the current erosion mitigation measures adopted by WMC. There has been no change to the regional terrain since the 1983 EIS, which forms the primary source for the information contained here.

H1 REGIONAL ENVIRONMENT—THE MOONDIEPITCHNIE ENVIRONMENTAL ASSOCIATION

To describe the Project Area in a regional context requires a land or terrain classification system that can specifically identify areas with similar environmental parameters. For the purposes of this EIS, the classification system of Laut et al. (1977) has been used. This system was selected to provide consistency with the original 1983 EIS and to:

- enable site-specific terrain mapping and impact prediction;
- overcome inconsistent terminology and mapping used by the different soil conservation boards encountered along infrastructure corridors.

Environmental associations are useful in describing the broad physical and ecological environments of a region. On a regional scale, Laut et al. (1977) have defined environmental associations that comprise a particular recurring combination or sequence of landforms with similar vegetation cover.

The region is dominated by the Moondiepitchnie environmental association, which comprises a large expanse of country (13,000 km^2) with the same basic features. The Project Area of approximately 300 km^2 (comprising the Special Mining Lease and Municipal Lease areas) occupies less than 2% of this association (Kinhill – Stearns Roger 1982). Therefore, in a regional context, the area that would be directly affected by Olympic Dam operations represents a small part of a widespread environment. The association is described as an undulating plain, often with extensive sand sheets, dunes and low silcrete-capped rises, featuring a mixed cover of tall open shrubland with a chenopod shrub or grass understorey, low chenopod shrubland, and woodland with a tussock grass understorey.

The primary characteristic of the Project Area is the sequence of more or less linear east–west oriented dunes of siliceous sand and swales in which the underlying soils are exposed. The dune sands contrast with the soils of the infrastructure corridors, which are generally loam or clay, frequently with a variable density gibber coating or covered by thin sand sheets. The spatial pattern of dune and swale soils results in a similarly pronounced pattern on the vegetation: dunes normally carry woodlands, while swales normally carry low shrublands (localised exceptions do occur).

This alternation of dune and swale, and of woodland and shrubland, creates a characteristic impression of the region as having a landscape that is highly variable over very small distances, but uniform and repetitious overall. Dune density (determined by spacing between crests) varies considerably, and accounts for a number of different terrain units and vegetation sequences throughout the dunefields. The Moondiepitchnie drainage is internal, draining into claypans and depressions between the sand ridges.

H2 TERRAIN

Within the region the landforms and soils form two distinct suites: those created by the weathering of the underlying rocks of Cambrian to Cretaceous age, and others of more recent aeolian origin that have been superimposed on the landscape. The underlying rocks consist of Arcoona Quartzite, Andamooka Limestone, and Cretaceous kaolinitic siltstones which, on a regional scale, are relatively flat-lying units.

Although past erosional cycles have removed varying thicknesses of these materials, the resulting surface remains essentially flat, consisting of an extensive stony tableland. In places where extensive deep erosion has occurred, claypans, swamps and lagoons have formed at the terminal points of the internal drainage systems.

The more recent Quaternary deposits form a thin veneer of aeolian origin over much of the tableland surface. In many places these deposits form the most dominant feature of the landscape, comprising a series of east–west oriented red quartz sand dunes. The dunes are highly variable, with heights of up to 10 m, widths to a maximum of 300 m, and dune spacing from about 100 m to several kilometres.

When closely spaced, the interdune areas form gentle concave swales covered with sandy soil and are often well-vegetated with trees and shrubs. Where dunes are more widely spaced, the tableland surface, with its more silty and clayey sandy soils, gibber and drainage features, is exposed.

The characteristics of the tableland surface vary considerably over the region, and depend on the underlying rock type and the thickness of the Quaternary sediments. In the majority of the Project Area the underlying rock type is Andamooka Limestone. In some areas the bedrock is very shallow, and outcrops occur in some places.

The tableland surface is generally undulating, with sandy textured soils and extensive occurrences of gibber in the swale areas. The soils contain large quantities of calcareous material, possibly derived from weathering of the underlying rock. Drainage is into claypans, vegetated shallow depressions or, occasionally, small dolines.

H2.1 Sand dune development and sand movement

Origin of dunefields

The dunes in the region form part of the Australian desert dunefield, which occupies about 20% of the continent. The dune systems in the Project Area were formed during a time of increased sand mobility in the Pleistocene Period when wind speeds at least 20% higher than present speeds were experienced in the region.

The dune ridges in the Project Area are longitudinal in form, with the direction being parallel to sand-shifting winds. The dominant sand-moving winds during the Pleistocene period would have been north-west and south-west, associated with anticyclonic pressure systems moving across the continent. These winds would have caused a zigzag movement of sand in an easterly direction, resulting in the general eastward trend of the dunes in the region. The present wind regime also results in a net easterly movement of sand.

Sand movement

At present, most of the dunefields experience few winds above the threshold velocity required for surface sand movement. As a result, the desert dunes of the Project Area, and Australia in general, show low mobility. Sand movement generally occurs following disturbance, and is confined to dune crests. Blowouts predominantly form following loss of vegetation cover owing to factors such as overgrazing, fires, or desiccation of groundcover in drier periods.

Experience in the Project Area indicates that sand movement occurs at a threshold velocity of approximately 5.5 m/s when measured 1 m above ground level, or 8.9 m/s when measured at 10 m above ground level (Kinhill – Stearns Roger 1982).

H2.2 Variations in dune density

There is considerable variation in dune density or spacing and, to some extent, dune orientation in the Project Area. These variations may be attributed to topographic influences that caused local variations in wind exposure during the Pleistocene Period, and which are also evident in the present day but on a smaller scale.

Landforms in the region and the Project Area are strongly influenced by the spacing of dunes. Table H.1 presents the landform types of the region, and identifies the relationship between dune density and landform type.

Table H.1 Landform types

Landform	Type	Description
Tableland	(1)	Almost flat tableland surface with no dune ridges present
Dissection slopes	(2)	Dissection slopes of the tableland surface with no dune ridges present
Drainage areas	(3)	Broad concave depressional drainage areas that can contain sand ridges
Widely spaced dunes	(4)	Almost flat tableland surface with less than 30% of the area being sand ridges
Moderately spaced dunes	(5)	Almost flat tableland surface with between 30% and 60% of the area consisting of sand ridges
Closely spaced dunes	(6)	Almost flat tableland surface with between 60% and 80% of the area covered by sand ridges

Four levels of dune density were defined: landform types 1, 2 and 3 all display little or no dune formation, while landform types 4, 5 and 6 indicate increasing density from 30% to 80% in area.

It would appear that in the more exposed parts of the tableland surface, dune ridges are generally widely spaced. In contrast, sand accumulation and closely spaced dunes occur on the eastern side of the lower areas, as these areas are more sheltered from prevailing winds and accumulate water-borne sediments.

H2.3 Terrain classification and mapping

In the Project Area, terrain can be categorised as follows:

- terrain units—the smallest landform units with consistent physiographic characteristics derived from a combination of slope class and soil type;
- terrain features—land units grouped by recognisable physical attributes of the landscape;
- terrain patterns—the broadest description of terrain used for mapping, based on geological formations and landform types.

The following sections describe the three categories of terrain and the relationships between each category.

Terrain units

Terrain units have simple surface forms, usually occur on a single rock or parent material type, and have, within reasonable limits, uniform soils or surficial materials. The terrain unit descriptors (Table H.2) show the divisions of slope range, slope form and soil type that have been used in the numerical referencing of the terrain units. These descriptors are the principal factors in determining susceptibility to erosion, and therefore form a suitable basis for assessing terrain-related impacts.

Terrain unit notation lists the physiographic type first and soil type last; for example, terrain unit 14 is a gently sloping tableland surface (physiographic description 1) with sandy soils showing moderate texture contrast (soil type 4). Some terrain units have a dual symbol for the soil referencing number, indicating that both soil types are likely to occur in close proximity within the unit. For example, terrain unit 50'4 is a gently undulating tableland surface (physiographic description 5) with rock outcrop on the rises (soil type 0) and sandy soils in the depressions (soil type 4), the apostrophe indicating a mixture of these two soil types.

Terrain features

For the purpose of discussing the susceptibility to erosion (for impact associated with terrain units), it is possible to consider similar types of terrain units together. Within the Project Area, six terrain features have been identified that summarise the range of terrain units present. These can be described as follows (related terrain units are shown in brackets):

- stony tableland (10'4, 50'4)—flat or very gently sloping tableland surface;
- narrow interdune corridors and sandy swales (13, 14, 10'4)—gently sloping, linear concave depressions between sand dune ridges;
- drainage depressions (03, 04, 06)—flat claypans, swamps, and very gently concave terminal drainage areas;
- low stony rises (20'4, 21, 21'4)—low stony elevated areas rising above the tableland by up to 3 m, usually siliceous and probably relict strandlines;
- dunefields (13, 32, 52, 53)—undulating dunefields, often with some linear ridges trending east–west but with no flat interdune tableland surfaces exposed;
- sand dune ridges (32, 42, 63)—linear sand dunes trending in an east–west direction and elevated above the tableland surface by up to 10 m.

Terrain patterns

The terrain pattern classification system consists of a simple alphanumeric coding combining the geological formations and landform types shown in Table H.3.

When using this system, terrain pattern A4, for example, refers to Andamooka Limestone tableland overlain by widely spaced sand ridges.

There are recognisable terrain features common to several terrain patterns. Table H.4 presents the terrain units, terrain features and terrain patterns that occur in the Project Area. Terrain patterns P1, P4 and Q3 occur as very small areas (less than 0.1%) on the margins of the Project Area.

Table H.2 Terrain unit descriptors

Physiography			Soil		
No.	Description	Slope range	No.	Type	Classification[1]
0	Flat, generally large drainage depressions subject to inundation, and minor stream channels and erosion gullies. Includes salt lakes, claypans and swamp areas	Flat	0	Rock outcrop and skeletal soils (0.3 m deep) on weathered rock	S
1	Very gently sloping planar tableland surfaces, often adjacent to drainage depressions	Generally less than 2%	1	Gravelly or stony soils, often on weathered rock	S
2	Broadly rounded convex plateau surfaces, often trending north–south across swales, forming the watershed between adjacent catchment areas and drainage depressions	Generally less than 2% but up to 5%	2	Uniform sands with little or no fines (silt or clay) content	LS
3	Broadly rounded crest areas of low dunes	Less than 10%	3	Sandy, uniform, gradational or weak texture contrast, coarse to medium-textured soils of low plasticity; calcareous silt often finely dispersed throughout the lower parts of the profile	SiCL SCL
4	More sharply rounded crest areas of higher dunes, often with depressed concave blowouts generally to the south	10–20%	4	Sandy soils showing moderate texture contrast, coarse to medium-textured, with calcareous silt either finely dispersed or in pockets	SiCL SCL
5	Elevated tableland surface, gently or sharply undulating, with generally up to 1 m relief but occasionally up to 2 m	Less than 10%	5	Sandy clay soils of low to medium plasticity, becoming very silty or gravelly at depth	LC
6	Gently to moderately sloping planar slopes below dune crests	10–30%	6	Clay soils of medium to high plasticity showing gradational profile or weak texture contrast; a thin surface veneer of coarser texture may occur locally. Often stratified layers of coarser texture and gypsum in the lower parts of the profile	LMC / HC

1 *Modified from Northcote (1984).*

Table H.3 Terrain patterns—geological formation and landform types

Geological formations			Landform types		
Formation		Description	Type		Description
Quaternary deposits	(Q)	Sand ridges and dunefields with interdunal corridors (swales) and claypans	Tableland	(1)	Almost flat tableland surface with no dune ridges present
	(Qs)	Sand ridges, dunefields and claypans superimposed on an older system of northerly trending, low stony rises or dunes	Dissection slopes	(2)	Dissection slopes of the tableland surface with no dune ridges present
Cretaceous siltstone	(K)	Kaolinitic siltstones, shales and sandstones, with cobbles	Drainage areas	(3)	Broad concave depressional drainage areas that can contain sand ridges
Andamooka Limestone	(A)	Dolomite limestone	Widely spaced dunes	(4)	Almost flat tableland surface with widely spaced sand ridges (up to 30% of the area of the pattern)
Arcoona Quartzite	(P)	Quartzite	Moderately spaced dunes	(5)	Almost flat tableland surface with between 30% and 60% of the area consisting of sand ridges
			Closely spaced dunes	(6)	Almost flat tableland surface with between 60% and 80% of the area covered by sand ridges

Table H.4 Occurrence of principal terrain categories in the Project Area

Terrain units	Terrain feature	Terrain patterns
10'4, 50'4	Stony tableland	P1
13, 14, 10'4	Narrow interdune corridors	Q4, Qs4, K4, A4; Q5, Qs5, A5
03, 04, 06	Drainage depressions	Q4, Qs4, K4, A4, P4
20'4, 21, 21'4	Low stony rises	Qs4, K4; Qs5, Q3, P4
13, 32, 52, 53	Dunefields	Q5, Qs5; Q6
32, 42, 63	Sand ridges	Q4, Qs4, K4, A4; Q5, Qs5, A5, P4

Terrain units' susceptibility to erosion

Most of the soils in the Project Area are susceptible to erosion by wind and/or water. Their combined stability is dependent on a number of features, including:

- percentage of silt and clay fines in the sand soils
- presence of gravel as a reinforcing material or as a surface shield (gibber)
- presence of a surface 'skin' over the silty sands of the interdune areas
- presence and type of vegetative cover.

The scale used for rating individual terrain units for susceptibility to erosion is given in Table H.5, and is based on field observations and on consideration of soil properties and surface slopes. Separate assessments have been made for susceptibility to erosion by wind and by water, and these are shown in Table H.6. The terrain units in this table have been grouped under the terrain features in which they usually occur. It is evident from Table H.6 that the main potential for surface disturbance is related to wind erosion of dunefields and sand ridges.

Table H.5 Rating of erosion susceptibility

Rating	Explanation	Implications
L – low susceptibility to erosion	Materials considered to be very resistant to natural disturbing forces, and containing no dispersive layers	No protection required after construction of roads or other structures that affect the land surface
M – moderate susceptibility	Materials that are often stable in the natural state, although erosion can be induced by destruction of inter-particle bonding, dispersion of clay materials or loss of vegetative cover. Erosion, when it occurs, is often confined to local areas	Consequences of erosion can vary considerably. Often only a thin surface layer of weakly bonded sand will be lost, but restoration of underlying stronger soils can be difficult in arid areas. Loss of material can lead to dust nuisance, rilling of the surface and silting of drainage structures
H – high susceptibility	Materials inherently unstable and relying totally on other mitigating factors for stability. Erosion, when it occurs, may influence other stable areas, causing deterioration and eventual soil loss	Consequences of erosion need to be determined, and management policies adopted that recognise and ensure integrity of mitigating factors

Table H.6 Erosion susceptibility of terrain units

Terrain units and description	Susceptibility to erosion[1]	
	Wind	Water
Stony tableland		
10'4, flat elevated tableland	L	L
50'4, gently undulating elevated tableland	L	L
Narrow interdune corridors and sandy swales		
13, thin sand spreads/gentle footslopes of dunes	M	L
14, flat to gently sloping swale of structured soils	L	M–L
10'4, flat swale of structured soils	L	L
Drainage depressions		
03, small depressions with sand sheets	M	L
04, longer depressions in swales, flood-prone	L	L
06, claypans	L	L
Low stony rises		
20'4, elevated gently rounded tableland with skeletal soils	L	L
21, elevated gently rounded tableland	L	L
21'4, elevated gently rounded tableland with gilgai	L	L
Dunefields		
13, thin sand spreads, gentle footslopes of dunes	M	L
32, broadly rounded flatter dunes	M–H	L
52, gently undulating sand sheets at higher elevations	M–H	L
53, gently undulating sand sheets at lower elevations	M	L

Table H.6 Erosion susceptibility of terrain units (continued)

Terrain units and description	Susceptibility to erosion[1]	
	Wind	Water
Sand ridges		
32, broadly rounded, flatter dunes	M–H	L
42, long, linear, higher dune ridges	M	L
63, steeply sloping footslopes of dunes	M–H	L

1 *Susceptibility to erosion ratings: L = low, M = medium, H = high (as detailed in Table H.5).*

H3 POTENTIAL FOR SOIL DISTURBANCE AND EROSION

The potential impacts for soil disturbance and erosion that could arise owing to development activity are summarised in Table H.7 for each of the terrain units. The table considers six types of pedestrian and vehicular activity in increasing intensity and generally increasing effect.

Low-intensity activities produce little effect on stony tablelands, drainage depressions and low stony rises; however, these activities can cause some surface disturbance in the interdune corridors. In dunefields, and particularly on sand ridges, deflation can result after loss or reduction of the vegetative cover even at relatively low intensities of activity.

Under more intense development activity involving heavy vehicles, breakdown of the soil surface can occur on stony tablelands, interdune corridors, drainage depressions and, to a lesser extent, the low stony rises. Under intense activity, dunefields and sand ridges can undergo greater degrees of deflation, which can lead to formation of drifts at very high intensities of activity.

Table H.7 Impacts of development activity on terrain features

Activity	Stony tablelands	Interdune corridors	Drainage depressions	Low stony rises	Dunefield sand spreads	Sand ridges
Light foot traffic	No effect	Breakup of surface skin	No effect	No effect	Little effect	Little effect
Concentrated foot traffic	No effect	Breakup of surface skin	No effect	No effect	Slight deflation, some breaking of low shrubs reducing erosion protection	More severe deflation, some breaking of low shrubs reducing erosion protection
Single vehicle	No effect	Breaking of vegetation and surface skin	No effect	No effect	Loss of vegetation and deflation	Some breaking of low shrubs reducing erosion protection
Multiple vehicles	Some rutting, particularly when wet. Prone to track erosion in sloping areas	Complete loss of vegetation, leaving surface exposed to erosion	Some rutting when wet	Little effect	Loss of vegetation and deflation	Loss of vegetation and deflation
Minor construction traffic	Breakup of surface	Loss of vegetation, breakup of surface	Breakup of surface	Little effect	Loss of vegetation and deflation	Loss of vegetation and deflation
Major construction traffic	Complete disturbance of surface, leading to erosion	Exposure of surfaces from which dispersion and run-off occur	Breakup of surface	Breakup of surface, otherwise little effect	Complete loss of vegetation, deflation and drifts	Complete loss of vegetation, deflation and drifts

The Draft EIS (Kinhill – Stearns Roger 1982) predicted the following probable direct effects for each of the terrain features if no mitigatory action were taken:

- stony tableland:
  - dust from trafficked areas
  - water erosion of channels on sloping surfaces;
- interdune corridors:
  - loss of silty sand surface and creation of hardpan;
- drainage depressions:
  - increased volume of dust and sand, which would blow out to the east;
- low, stony rises:
  - little effect;
- dunefields and sand spreads:
  - with loss of vegetation sand would become mobile, with a general sand movement to the east;
- sand ridges:
  - with loss of vegetation sand would become mobile, with a general sand movement to the east along dune ridges;
  - after deflation of a ridge to several metres, the effect of wind would tend to be reduced by more erosion-resistant sands and by the width of the deflation zone, unless development activity continued in the area.

Mitigating action undertaken by WMC ensured that the above predicted impacts did not occur or were minimised. An environmental review (WMC—Olympic Dam Corporation 1995) concluded that:

- retention of vegetation and management of roads and tracks had resulted in minimal, if any, increase in the normal background sand movement;
- mobile sand was a natural phenomenon that still occurred from time to time, but there appeared to have been little or no increase in sand movement to the east;
- stabilisation following deflation was supported by the presence of numerous stable blowouts that pre-date project activities (there was no evidence of such blowouts having occurred since WMC commenced activities in this area).

WMC's current practice of adopting mitigatory procedures in mine construction and operations and township development would continue to ensure minimal impacts to terrain features.

Table H.8 summarises the potential impacts associated with each terrain pattern type found within the Project Area, together with the mitigation measures currently adopted by WMC to ameliorate adverse effects.

Experience has shown that all the potential terrain-related impacts are amenable to mitigation, either through suitable planning and design of the development or through the control of construction activities. For example, potential sand movement can be controlled by retention of vegetation where practicable, and by stabilising any areas that show sand drift or where dune ridges would be disturbed. Dust generation owing to surface breakdown of trafficked areas on tablelands can be controlled by either sheeting with gravel or watering.

Table H.8 Potential impacts and current mitigation measures for terrain patterns

Terrain pattern	Landform type and range of impacts	Mitigation measures
A1, K1, P1	Tableland:	
	• Interception and concentration of surface flows	• Keep drainage dispersed where possible
	• Erosion of dispersive soils (P1 and K1)	• Retain surface gibbers or channel flows through stabilised or lined drains. Roll rather than grade temporary access tracks
	• Rutting of surface by construction traffic in wet weather	• Provide pavements where possible for construction traffic
	• Dust from trafficked areas	• Either provide sheeted surfaces and pavements for traffic or water unsheeted areas
A2, K2, P2	Dissection slopes:	
	• Interception of surface flows	• Provide pipes, culverts and similar
	• Channelling of flows alongside embankments or trenches	• Ensure adequate drainage through embankments, and stabilise soil surface
	• Scarring and erosion of surfaces caused by difficult working conditions	• Minimise construction traffic and confine to prepared access roads
	• Alteration to sediment movement pattern	• Keep drainage lines open where practicable, and avoid re-routing
A3, K3, P3, Q3	Drainage areas:	
	• Alteration to areas of swamplands and claypans	• Ensure construction works in catchment areas do not affect drainage
	• Accelerated erosion due to erection of structures within drainage channels	• Place footings outside channels where practicable, or provide adequate protection for footings
A4, K4, P4, Qs4	Widely spaced dunes:	
	• Loss of vegetation leading to increased sand movement generally	• Avoid unnecessary removal of vegetation
	• Localised sand movements caused by construction of corridors through dune ridges	• Stabilise potential erosion areas
	• Alteration to drainage pattern within swales	• Provide adequate drainage through any barriers created across swales
	• Alteration to sediment movement towards terminal drainage points in swales	• Engineer drainage facilities to reduce ponding and associated sediment build-up
	• Creation of hardpan surfaces	• Retain saltbush and bluebush in swales where practicable
	• Loss of sand from windward side of structures	• Provide stabilised or sheeted pavements in areas where deflation is likely to occur
A5, K5, P5, Q5, Qs5	Moderately spaced dunes:	
	• Loss of vegetation, leading to increased sand movement	• Refrain from removal of vegetation
	• Localised sand movement caused by construction of corridors through dune ridges	• Stabilise potential erosion areas

Table H.8 Potential impacts and current mitigation measures for terrain patterns (continued)

Terrain pattern	Landform type and range of impacts	Mitigation measures
	• Creation of hardpan surfaces	• Retain saltbush and bluebush in swales; where hardpan occurs, cover with sand
	• Loss of sand from windward side of structures	• Provide stabilised or sheeted pavements in areas where deflation is likely to occur
A6, K6, Q6, Qs6	Closely spaced dunes:	
	• Loss of vegetation leading to increased sand movement	• Refrain from removal of vegetation
	• Localised sand movement caused by construction of corridors through dune ridges	• Stabilise potential erosion areas
	• Loss of sand from windward side of structures	• Provide stabilised or sheeted pavements in areas where deflation is likely to occur

The Roxby Downs town site is in Q5 (moderately spaced dunefield of Quaternary deposits) and Q6 (closely spaced dunefield of Quaternary deposits), which exhibit the characteristics described below.

Within the Q5 pattern the dunes are sheltered and well vegetated. WMC's policy of retention of vegetation and revegetation would continue to be an important factor in erosion mitigation for future development of Roxby Downs, and vegetation on the dune ridges adjacent to buildings would be safeguarded against uncontrolled access.

In the Q6 pattern, where dune ridges coalesce into sand spreads and dunefields with only vaguely preferred orientation, areas of potential instability are harder to predict. Generally, these areas appear more stable than sand in the Q5 type dunes, but this is probably because these large sand accumulations are not subjected to the stronger winds occurring on the ridges of the more exposed tableland surfaces.

In relation to impacts, the terrain features present in the town site have been assessed for general suitability for future development as follows:

- Interdune corridors and swales: These are suitable in the more elevated, drained areas, although filling would probably be required in lower parts prior to construction of roads and buildings. Many of the swale surfaces are subject to minor infrequent inundation, and proper design would be necessary to ensure that water did not remain after periods of heavy rain.
- Drainage depressions: Without significant drainage alterations these are unsuitable for buildings. Road access can be achieved with filling, although the subsequent alteration to drainage patterns would need evaluation at the final design stage.
- Low dune ridges and sand sheets: These are suitable for development, providing vegetative cover is retained or appropriate stabilisation is undertaken.
- Sand ridges: These are generally unsuitable for development. Part III of The Far North Development Plan (Department of Housing and Urban Development 1996) expressly restricts development on sand ridges.

H4 SURFACE HYDROLOGY

The Olympic Dam area is a mosaic of small closed catchments that range in area from 10 ha to 300 ha. There are no well-defined watercourses within the Project Area, although some of the closed catchments have discernible drainage lines at points where water flows into the terminal claypans.

Typically, each catchment consists of:

- a catchment boundary formed by the crests of sand dunes, which carry the dominant woody vegetation of the area and which overlie the clay soils. Moisture infiltration is rapid;
- an upper interdune corridor (swale), which may either carry sparse saltbush or be unvegetated. Soils in these areas tend to be a clay, silty-clay or clay loam, with low moisture infiltration capacities;
- a lower, terminal drainage depression, frequently a claypan, the surface of which is bare or covered with gibbers. Many of the lower pan areas show a strong mosaic of polygonal cracking through which surface water may initially infiltrate rapidly into the clay soil. On wetting, the dry clay swells causing the cracks to disappear and effectively 'seal' the surface against further entry of infiltrated water.

Catchment areas and grades are inadequate to generate sufficient run-off to form incised drainage channels such as those found in larger catchments north of Olympic Dam. Surface water movement is predominantly by overland flow over relatively short distances within closed catchments. Extreme rainfall events result in considerable surface ponding in the depressions and claypans.

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APPENDIX

FLORA

APPENDIX I

FLORA

This appendix provides background and supplementary information related to the flora of the region and the Project Area. The appendix is divided into two sections: Section I1, Regional vegetation, and Section I2, Introduced plants.

I1 REGIONAL VEGETATION

Three regional vegetation communities are present, namely:

- dunefield vegetation
- drainage area vegetation
- stony tableland vegetation.

These communities are also present in the Project Area.

A description of each of these communities is provided in the following text and presented graphically in Figures I.1a and I.1b.

I1.1 Dunefield vegetation

The primary vegetation communities in the region are those associated with the dunefields, which are the dominant landform. This vegetation comprises a repetitive sequence of low woodland/tall shrubland grading into a treeless, low shrubland between the dunes (Kinhill – Stearns Roger 1982).

Three types of dunefields have been identified in the region—those with closely spaced dunes, those with medium density dunes, and those with widely spaced dunes. Dunefields associated with stony tablelands are also present in the region, although generally in association with the Andamooka Limestone stony tablelands east of the Project Area.

The depth of sand over the underlying structured soils determines the type of vegetation present; hence, dunefields with different dune spacings often have a different suite of species. The vegetation of the dunefields forms two distinct groups—species associated with sandy soils and species associated with structured soils (generally in dune swales).

Areas of closely spaced dunes are scattered throughout the region. These areas are dominated by horse mulga *(A. ramulosa)* woodland on the dune ridges, with mulga *(A. aneura* and *A. cibaria)* in the narrow sandy swales or interdune depressions, or white cypress pine *(Callitris glaucophylla)* woodlands on the dune ridges and slopes as a continuous low open woodland (Kinhill – Stearns Roger 1982).

Other species associated with these communities include bullock bush *(Alectryon oleifolius* subsp. *canescens)* and narrow-leaved hopbush *(Dodonaea viscosa* subsp. *angustissima)* in small groves or as individuals on the dune ridges; bladder saltbush *(Atriplex vesicaria)* in the swales; and grass species, such as *Aristida holathera, A. contorta, Paractaenum refractum* and *Eriachne helmsii.*

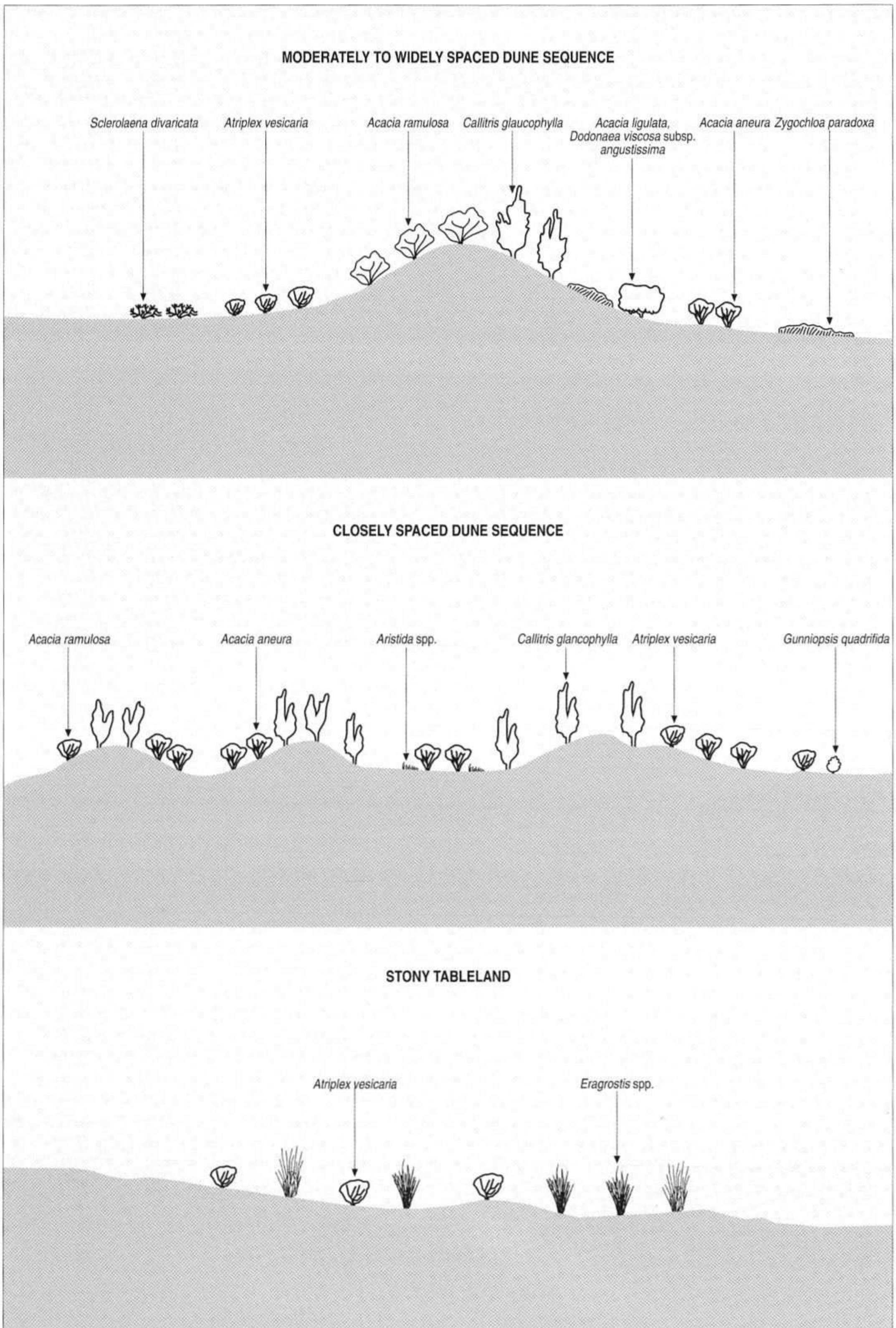

FIGURE I.1a
REGION AND PROJECT AREA VEGETATION COMMUNITIES

Not to scale

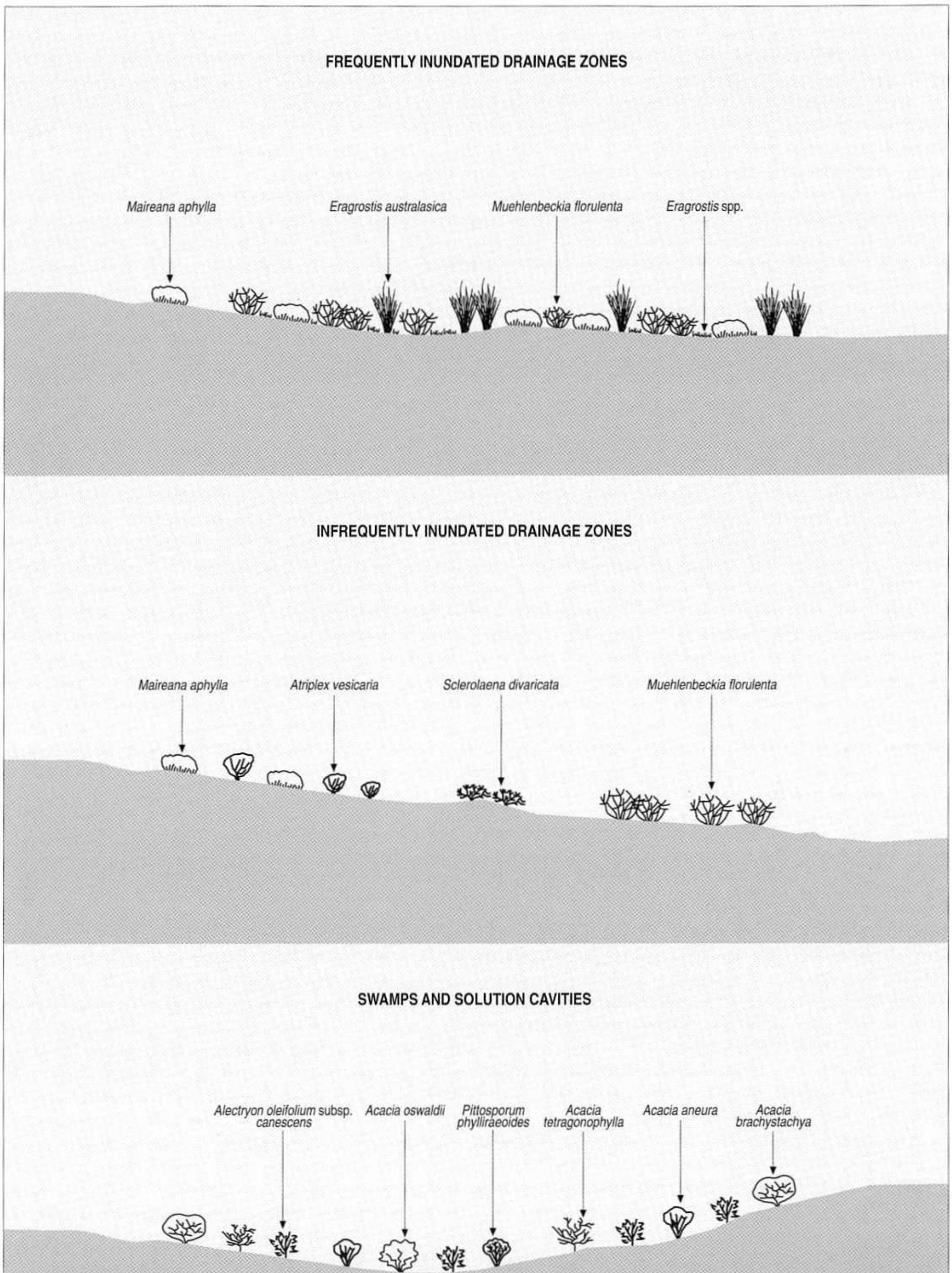

FIGURE I.1b
REGION AND PROJECT AREA VEGETATION COMMUNITIES

Not to scale

The vegetation communities associated with medium to low density dunes are horse mulga woodland/sandhill wattle *(Acacia ligulata)* tall open shrubland or mulga woodland on the dune ridges and dune footslopes, and bladder saltbush/low bluebush *(Maireana astrotricha)* low open shrubland on the flat to gently sloping swales.

Other species associated with this community include narrow-leaved hopbush and occasional groves of white cypress pine or western myall *(Acacia papyrocarpa)* on the dune ridges, *Aristida* spp. and bullock bush on the dune slopes, and *Enneapogon* spp. in association with the low shrublands of the interdune areas.

I1.2 Drainage area vegetation

Large drainage areas are generally present south and west of the Project Area, although small, localised drainage areas are present in the Project Area and the stony tablelands to its east.

Areas subject to flooding within the dunefields contain a distinctive vegetation, the floristic composition of which is dependent on the frequency of inundation, the salinity of soils and the terrain morphology.

Frequently inundated areas tend to be swampy and dominated by cane-grass *(Eragrostis australasica)* and lignum *(Muehlenbeckia florulenta)*. The groundcover is dominated by short perennial grasses such as *E. setifolia* and *E. falcata*.

Drainage areas less frequently inundated than the cane-grass swamps are dominated by cottonbush *(Maireana aphylla)* low open, and occasionally open, shrubland. Lignum is also present in the lower lying areas, while bladder saltbush and poverty-bush *(Sclerolaena divaricata)* are present on higher ground. Cottonbush shrubland often dominates the margins of cane-grass/lignum swamp areas.

The most dense vegetation in the region is associated with swamps and solution cavities in the Andamooka Limestone. These landforms are dominated by mulga *(Acacia cibaria,* and less frequently *A. aneura)* with bullock bush, dead finish *(A. tetragonophylla)*, umbrella wattle *(A. oswaldii)* and native apricot *(Pittosporum phylliraeoides)*.

I1.3 Stony tableland vegetation

This landform with associated vegetation is generally present 3 km or more east of the Project Area; however, a small area is located within 2 km of the eastern boundary fence.

The landform is typically dominated by bladder saltbush low open shrubland, although much of this community has degraded to *Eragrostis falcata, E. setifolia* and ephemeral species owing to drought and grazing. Other species associated with this community include *Sclerolaena* spp., *Frankenia serpyllifolia, Minuria cunninghamii, Ixiolaena leptolepis, Sporobolus actinocladus* and other herbs and grasses in localised depressions associated with cracking clay soils (e.g. gilgai soils). Trees and tall shrubs are generally absent from this community.

I1.4 Plant species associated with the region

Table I.1 provides a list of plant species associated with the vegetation communities of the region, while Table I.2 provides a comparison of species recorded in Kinhill – Stearns Roger (1982) with species recorded during ongoing monitoring.

Table I.1 Plant species associated with vegetation communities

Community	Common name	Species name
LOW DENSITY DUNEFIELD		
Dune ridge	Horse mulga	*Acacia ramulosa*
	Sandhill wattle	*A. ligulata*
	Western myall	*A. papyrocarpa*
	Narrow-leaved hopbush	*Dodonaea viscosa* spp. *angustissima*
	White cypress pine	*Callitris glaucophylla*
Dune slopes		*Aristida* spp. (mainly *A. holathera*)
	Mulga	*Acacia aneura*
	Bullock bush	*Alectryon oleifolius* subsp. *canescens*
Swale	Bladder saltbush	*Atriplex vesicaria*
	Low bluebush	*Maireana astrotricha*
		Enneapogon spp. (mainly *E. avenaceus*)
MEDIUM DENSITY DUNEFIELD		
Dune ridge	Horse mulga	*Acacia ramulosa*
	Sandhill wattle	*A. ligulata*
	Narrow-leaved hopbush	*Dodonaea viscosa* subsp. *angustissima*
	Silver cassia	*Senna artemisioides*
	Western myall	*Acacia papyrocarpa*
	White cypress pine	*Callitris glaucophylla*
Dune slopes	Mulga	*Acacia aneura*
	Mulga	*A. cibaria*
Swale	Bladder saltbush	*Atriplex vesicaria*
	Low bluebush	*Maireana astrotricha*
	Bluebush	*M. sedifolia*
		Enneapogon spp. (mainly *E. avenaceus*)
CLOSELY SPACED DUNEFIELD		
Dune ridge	Horse mulga	*Acacia ramulosa*
	Mulga	*A. aneura*
	Mulga	*A. cibaria*
	White cypress pine	*Callitris glaucophylla*
	Bullock bush	*Alectryon oleifolius* subsp. *canescens*
	Narrow-leaved hopbush	*Dodonaea viscosa* subsp. *angustissima*
Swale	Bladder saltbush	*Atriplex vesicaria*
		Aristida holathera
		A. contorta
		Paractaenum refractum
		Eragrostis setifolia
STONY TABLELAND DUNEFIELD		
Dune ridge	Sandhill wattle	*Acacia ligulata*
	Narrow-leaved hopbush	*Dodonaea viscosa* subsp. *angustissima*
	White cypress pine	*Callitris glaucophylla*
	Horse mulga	*A. ramulosa*
	Bullock bush	*Alectryon oleifolius* subsp. *canescens*
Interdune depressions	Mulga	*Acacia aneura*
	Mulga	*A. cibaria*

Table I.1 Plant species associated with vegetation communities (continued)

Community	Common name	Species name
ANDAMOOKA LIMESTONE PLATEAUX AND STONY TABLELANDS		
Andamooka Limestone plateaux	Bluebush	*Maireana sedifolia*
	Bladder saltbush	*Atriplex vesicaria*
	Silver mulla mulla	*Ptilotus obovatus*
		Sclerolaena spp.
	Silver cassia	*Senna artemisioides*
Stony tableland	Bladder saltbush	*Atriplex vesicaria*
	Low bluebush	*Maireana astrotricha*
		Enneapogon avenaceus
		Eragrostis spp.
		Sclerolaena spp.
		Frankenia serpyllifolia
		Ixiolaena leptolepis
		Sporobolus actinocladus
DRAINAGE AREA VEGETATION		
Frequently inundated	Cane-grass	*Eragrostis australasica*
	Tea-tree	*Melaleuca pauperiflora*
	Lignum	*Muehlenbeckia florulenta*
		Eragrostis setifolia
		E. xerophila
		E. falcata
Infrequently inundated	Cottonbush	*Maireana aphylla*
	Lignum	*Muehlenbeckia florulenta*
	Bladder saltbush	*Atriplex vesicaria*
	Poverty-bush	*Sclerolaena divaricata*
Swamps/solution cavities	Mulga	*Acacia cibaria*
	Mulga	*A. aneura*
	Bullock bush	*Alectryon oleifolius* subsp. *canescens*
	Dead finish	*Acacia tetragonophylla*
	Umbrella wattle	*A. oswaldii*
	Native apricot	*Pittosporum phylliraeoides*

Table I.2 Comparison of species recorded in Kinhill – Stearns Roger (1982) and during the ongoing WMC vegetation monitoring programme

Common name	Family	Species name[1]	Recorded in 1982	Recorded during monitoring
Sturts pigface	Aizoaceae	*Gunniopsis quadrifida*	X	–
Karkalla		*Carpobrotus rossii**	X	–
Native spinach		*Tetragonia eremaea*	X	X
Red spinach		*Trianthema triquetra*	–	X
Large-flowered amaranth	Amaranthaceae	*Amaranthus grandiflorus*	X	X
Silver mulla mulla		*Ptilotus obovatus*	X	X
Long-tails		*P. polystachyus*	X	–
Salvation jane	Boraginaceae	*Echium plantagineum*[2]	X	–
Burr stickseed		*Omphalolappula concava*	–	X
Cattle bush		*Trichodesma zeylanicum*	X	X
	Campanulaceae	*Wahlenbergia* sp.	X	–

Table I.2 Comparison of species recorded in Kinhill – Stearns Roger (1982) and during the ongoing WMC vegetation monitoring programme (continued)

Common name	Family	Species name[1]	Recorded in 1982	Recorded during monitoring
Fan saltbush	Chenopodiaceae	*Atriplex angulata*	–	X
Spreading saltbush		*A. limbata*	X	–
Baldoo		*A. lindleyi*	–	X
Baldoo		*A. lindleyi* subsp. *inflata*	X	–
Pop saltbush		*A. spongiosa*	X	X
Sandhill saltbush		*A. velutinella*	X	X
Bladder saltbush		*A. vesicaria*	X	X
Nitre goosefoot		*Chenopodium nitrariaceum*	X	–
Clammy goosefoot		*C. pumilio*	–	X
Ball bindyi		*Dissocarpus paradoxus*	X	X
Climbing saltbush		*Einadia nutans* subsp. *nutans*	X	–
Ruby saltbush		*Enchylaena tomentosa*	X	X
Woolly-fruit copperburr		*Eriochiton sclerolaenoides*	X	X
Brown-headed samphire		*Halosarcia indica* subsp. *leiostachya*	X	–
Cottonbush		*Maireana aphylla*	X	–
Low bluebush		*M. astrotricha*	X	X
Small-leaved bluebush		*M. brevifolia*	X	–
Hairy fissure-weed		*M. ciliata*		
Rosy bluebush		*M. erioclada*	–	X
Satiny bluebush		*M. georgei*	X	–
Erect mallee bluebush		*M. pentatropis*	X	–
Black bluebush		*M. pyramidata*	X	–
Bluebush		*M. sedifolia*	X	–
Goat-head		*Malacocera tricornis*	X	–
Water weed		*Osteocarpum acropterum* var. *acropterum*	X	–
Spiny saltbush		*Rhagodia spinescens*	X	–
Buck bush		*Salsola kali*	X	X
Short-winged copperburr		*Sclerolaena brachyptera*	X	X
Green copperburr		*S. decurrens*	X	X
Grey copperburr		*S. diacantha*	X	X
Poverty-bush		*S. divaricata*	X	X
Poverty-bush		*S. intricata*	X	–
Woolly copperburr		*S. lanicuspis*	X	X
Limestone copperburr		*S. obliquicuspis*	X	X
Spear-fruit copperburr		*S. patenticuspis*	X	–
Salt copperburr		*S. ventricosa*	X	X
Slender glasswort		*Sclerostegia tenuis*	X	–
Dwarf cup-flower	Compositae (Asteraceae)	*Angianthus pusillus*	X	X
Variable daisy		*Brachycome ciliaris*	X	X
Hard-headed daisy		*B. lineariloba*	–	X
Billybuttons		*Calocephalus platycephalus*	–	X
Showy burr-daisy		*Calotis cymbacantha*	–	X
Bogan flea		*C. hispidula*	–	X

Table I.2 Comparison of species recorded in Kinhill – Stearns Roger (1982) and during the ongoing WMC vegetation monitoring programme (continued)

Common name	Family	Species name[1]	Recorded in 1982	Recorded during monitoring
Woolly-headed burr-daisy		*C. multicaulis*	–	X
Ground-heads		*Chthonocephalus pseudevax*	–	X
		Craspedia sp.	X	–
Soft billybuttons		*C. pleiocephala*	–	X
Erect yellow-heads		*Gnephosis arachnoidea*	–	X
Stalked Ixiolaena		*Ixiolaena leptolepis*	X	–
Bush minuria		*Minuria cunninghamii*	–	X
Woolly minuria		*M. denticulata*	X	–
Minnie daisy		*M. leptophylla*	X	X
Fleshy groundsel		*Othonna gregorii*	–	X
Poached-egg daisy		*Polycalymma stuartii*	–	X
Cudweed		*Pseudognaphalium luteoalbum*	–	X
Common white sunray		*Rhodanthe floribunda*	–	X
Clustered sunray		*R. microglossa*	–	X
Musk sunray		*R. moschata*	–	X
Pigmy sunray		*R. pygmaea*	–	X
Slender sunray		*R. stricta*	–	X
Variable groundsel		*Senecio lautus*	–	X
Fuzz weed		*Vittadinia eremaea*	–	X
Australian bindweed	Convolvulaceae	*Convolvulus erubescens*	X	–
Dense crassula	Crassulaceae	*Crassula colorata*	–	X
Wild stock	Cruciferae (Brassicaceae)	*Blennodia pterosperma*	–	X
Long-fruited wild turnip		*Brassica tournefortii*[2]	X	X
Hairypod cress		*Harmsiodoxa blennodioides*	–	X
Green peppercress		*Lepidium oxytrichum*	–	X
Veined peppercress		*L. phlebopetalum*	–	X
		Menkea crassa	–	X
Narrow thread-petal		*Stenopetalum lineare*	–	X
Paddy melon	Cucurbitaceae	*Citrullus colocynthis*[2]	–	X
Bitter melon		*C. lanatus*[2]	X	–
White cypress pine	Cupressaceae	*Callitris glaucophylla*	X	X
Caustic weed	Euphorbiaceae	*Euphorbia drummondii*	X	X
Desert spurge		*E. tannensis*	X	–
Wheelers spurge		*E. wheeleri*	–	X
Sand spurge		*Phyllanthus fuernrohrii*	X	–
Bristly sea-heath	Frankeniaceae	*Frankenia serpyllifolia*	X	X
Spike centaury	Gentianaceae	*Centaurium spicatum*[2]	–	X
Common storks bill		*Erodium cicutarium*	–	X
Blue storks bill	Geraniaceae	*E. cygnorum*	X	X
Serrated goodenia	Goodeniaceae	*Goodenia cycloptera*	X	–
Stiff goodenia		*G. lunata*	–	X
Scrambled eggs		*G. pinnatifida*		–
	Gramineae (Poaceae)	*Aristida* spp.	–	X
Mulga grass		*A. contorta*	X	X

Table I.2 Comparison of species recorded in Kinhill – Stearns Roger (1982) and during the ongoing WMC vegetation monitoring programme (continued)

Common name	Family	Species name[1]	Recorded in 1982	Recorded during monitoring
Kerosene grass		*A. holathera* subsp. *holathera*	X	X
		Astrebla spp.	X	–
Button grass		*Dactyloctenium radulans*	X	X
Common bottle-washers		*Enneapogon avenaceus*	X	X
Jointed nineawn		*E. cylindricus*	X	X
Leafy nineawn		*E. polyphyllus*	X	X
Cane-grass		*Eragrostis australasica*	X	–
Mulka grass		*E. dielsii*	X	X
Sickle lovegrass		*E. falcata*	X	–
Hairy flowered woollybutt		*E. laniflora*	X	X
Neverfail		*E. setifolia*	X	X
Knotty-butt neverfail		*E. xerophila*	–	X
Woollybutt wanderrie		*Eriachne helmsii*	X	X
Window mulga-grass		*Neurachne munroi*	X	–
		Panicum sp.	X	–
Barbed-wire grass		*Paractaenum novae-hollandiae*	X	X
Bristle-brush grass		*P. refractum*	X	X
		Paspalidium constrictum	–	X
Tiny bristle grass		*Rostraria pumila*[2]	–	X
Arabian grass		*Schismus barbatus*[2]	–	X
Ray grass		*Sporobolus actinocladus*	X	X
Balcarra grass		*Stipa nitida*	X	X
Burr-grass		*Tragus australianus*	X	X
Five-minute grass		*Tripogon loliiformis*	X	–
Purple heads		*Triraphis mollis*	X	X
Large armgrass		*Urochloa praetervisa*	X	–
Sandhill cane-grass		*Zygochloa paradoxa*	X	–
Grey germander	Labiatae (Lamiaceae)	*Teucrium racemosum*	X	–
Mulga	Leguminosae	*Acacia aneura*	X	X
Umbrella mulga		*A. cibaria*	X	–
Witchetty bush		*A. kempeana*	X	–
Sandhill wattle		*A. ligulata*	X	X
Umbrella wattle		*A. oswaldii*	X	–
Western myall		*A. papyrocarpa*	X	–
Horse mulga		*A. ramulosa*	X	–
Dead finish		*A. tetragonophylla*	X	–
Birdflower		*Crotalaria cunninghamii*	X	–
Bluebush pea		*C. eremaea* subsp. *eremaea*	X	–
		Indigofera helmsii	X	–
Redflower lotus		*Lotus cruentus*	–	X
Desert cassia		*Senna artemisioides* subsp. *coriacea*	X	–
Woody cassia		*S. artemisioides* subsp. *petiolaris*	X	–
Wild violet		*Swainsona adenophylla*	X	–
Sturt's desert-pea		*S. formosa*[1]	X	X
		S. oliveri	–	X

Table I.2 Comparison of species recorded in Kinhill – Stearns Roger (1982) and during the ongoing WMC vegetation monitoring programme (continued)

Common name	Family	Species name[1]	Recorded in 1982	Recorded during monitoring
Mulga trefoil		*Tephrosia sphaerospora*	X	–
Onion weed	Liliaceae	*Asphodelus fistulosus*[2]	–	X
Fringe-lily		*Thysanotus exiliflorus*	–	X
Harlequin mistletoe	Loranthaceae	*Lysiana exocarpi*	X	–
Mulga mistletoe		*L. murrayi*	X	–
Desert chinese lantern	Malvaceae	*Abutilon otocarpum*	X	X
Velvet-leaved hibiscus		*Hibiscus krichauffianus*	X	–
Malvastrum		*Malvastrum americanum*[2]	X	–
Sand sida		*Sida ammophila*	X	X
Corrugated sida		*S. corrugata* vars.	X	–
Pin sida		*S. fibulifera*	X	X
Common nardoo	Marsileaceae	*Marsilea drummondii*	X	–
Budda	Myoporaceae	*Eremophila duttonii*	X	–
Tar bush		*E. glabra*	X	–
Crimson turkey-bush		*E. latrobei*	X	–
Emubush		*E. longifolia*	X	–
		E. paisleyi	X	–
Turpentine bush		*E. sturtii*	X	–
Tea-tree	Myrtaceae	*Melaleuca pauperiflora*	X	–
Broom bush		*M. uncinata*	X	–
	Nyctaginaceae	*Boerhavia diffusa*	X	–
Tar-vine		*B. dominii*	–	X
Large adders tongue	Ophioglossaceae	*Ophioglossum polyphyllum*	–	X
Native apricot	Pittosporaceae	*Pittosporum phylliraeoides*	X	–
Sago weed	Plantaginaceae	*Plantago drummondii*	–	X
Lignum	Polygonaceae	*Muehlenbeckia florulenta*	X	–
Small purslane	Portulacaceae	*Calandrinia eremaea*	–	X
Round-leaved parakeelya		*C. remota*	X	X
Munyeroo		*Portulaca oleracea*	X	X
Needle bush	Proteaceae	*Hakea leucoptera*	X	–
Leafless ballart	Santalaceae	*Exocarpus aphyllus*	X	–
Quandong		*Santalum acuminatum*	X	–
Plumbush		*S. lanceolatum*	X	–
Narrow-leaved hopbush	Sapindaceae	*Dodonaea viscosa* subsp. *angustissima*	X	–
Bullock bush		*Alectryon oleifolius* subsp. *canescens*	X	X
Bluerod	Scrophulariaceae	*Stemodia floribunda*	X	–
Australian boxthorn	Solanaceae	*Lycium australe*	X	–
Tree tobacco		*Nicotiana glauca*[2]	X	–
		Solanum spp.	X	–
Velvet potato bush		*S. ellipticum*	–	X
Western tar-vine	Sterculiaceae	*Gilesia biniflora*	–	X
Native carrot	Umbelliferae (Apiaceae)	*Daucus glochidiatus*	–	X
Caltrop	Zygophyllaceae	*Tribulus terrestris*	X	–

Table I.2 Comparison of species recorded in Kinhill – Stearns Roger (1982) and during the ongoing WMC vegetation monitoring programme (continued)

Common name	Family	Species name[1]	Recorded in 1982	Recorded during monitoring
Shrubby twinleaf		*Zygophyllum aurantiacum*	X	–
Sand twinleaf		*Z. ammophilum*	–	X
Climbing twinleaf		*Z. eremaeum*	–	X
Clasping twinleaf		*Z. howittii*	–	X

1 *Nomenclature: Generally Jessop and Toelken (1986) and Jessop (1993).*
2 *Denotes introduced species.*
**Probably misidentified in Kinhill – Stearns Roger (1982).*

I2 INTRODUCED PLANTS

Introduced plants in the region (and generally) are spread by:

- transportation of plants' reproductive material (e.g. seeds) by means such as wind, water, and on vehicles, equipment, footwear, clothing and animals;
- dumping of garden wastes containing ornamental or introduced plants;
- contaminated materials such as lawn, pasture, rabbit bait and bird seeds, and potting soil in plant tubes and pots.

Badman (1995) and Parsons and Cuthbertson (1992) indicate that the colonisation of pest plants in the arid zone is reliant on a number of factors, including the:

- season, duration and amount of rainfall
- ability of the plant to disperse its seeds
- shade provided by the existing vegetation canopy
- available ecological niches
- lack of competition from native plant species
- any combination of these factors.

Introduced species

Introduced species are generally plant species that have been deliberately introduced from overseas for use as garden plants (ornamental) or in agriculture or horticulture. For example, buffel grass *(Cenchrus ciliaris)* was introduced in the 1950s as a pasture species and for erosion control, and athel pine *(Tamarix aphylla)* was introduced in the early 1900s as a salt-tolerant shade tree (McLennan 1996). These species are now considered major pests in areas of northern Australia, including northern South Australia. Accidental introductions have also occurred through the import of materials contaminated with introduced species (Carr et al. 1992).

Commonwealth and State collaborative programmes established to assist control of introduced plants include:

- formal recognition of some introduced plants and some plant pathogens as a major threatening process to biodiversity, and establishment of policy guidelines for introduced plant and plant pathogen control by the Department of the Environment, Sport and Territories (1996);
- the National Landcare Program, which includes the development of programmes to control land degradation processes, including the presence of noxious weeds;
- the Save the Bush Program, which includes pest control for the conservation of vegetation communities and habitats.

Table I.3 presents introduced plant species of major concern in the region and northern South Australia generally, including proclaimed plant species defined under the South Australian *Animal and Plant Control (Agricultural and Other Purposes) Act 1986.* Table I.4 provides a list of plant species recorded for the region and the Project Area.

Table I.3 Introduced plant species of major concern in the region and northern South Australia, including proclaimed species[1]

Common name	Family	Species name	Classification in SA	Distribution/Concern
Khaki weed	Amaranthaceae	*Alternanthera pungens*	SA Class 1 noxious weed	
Rubber bush	Asclepiadaceae	*Calotropis procera*	NT Class B & C noxious weed; environmental weed (northern Australia)	Northern SA in Ghan railway line borrow pits
Salvation jane (Patersons curse)	Boraginaceae	*Echium plantagineum*	SA Class 3 noxious weed	Widespread in SA
Smooth heliotrope		*Heliotropium curassavicum*		Widespread in the pastoral zone
Prickly pear	Cactaceae	*Opuntia* spp.	SA Class 1 noxious weed	
Fat hen	Chenopodiaceae	*Chenopodium album*		Urban areas
Capeweed	Compositae (Asteraceae)	*Arctotheca calendula*		Ubiquitous distribution in SA
Wild aster		*Aster subulatus*		Urban areas
Field marigold		*Calendula arvensis*		Throughout much of SA
Maltese cockspur		*Centaurea melitensis*		Throughout much of SA
Flaxleaf fleabane		*Conyza bonariensis*		Roadsides and built-up areas
Gazania		*Gazania linearis*	Environmental weed; SA Category 2—serious threat	
Clammy sow-thistle		*Sonchus tenerrimus*		Widespread in the pastoral zone
Noogoora burr		*Xanthium occidentale*	SA Class 2 noxious weed	Spread from Queensland by seeds in Cooper Creek and by stock/fodder
Bathurst burr		*X. spinosum*	SA Class 2 noxious weed	
Long-fruited wild turnip	Cruciferae (Brassicaceae)	*Brassica tournefortii*		Ubiquitous in SA
Wards weed		*Carrichtera annua*	Environmental weed; SA Category 1—very serious threat	Along Oodnadatta Track; spread is similar to *Brassica tournefortii* but not as common in Project Area
Short-fruited wild turnip		*Rapistrum rugosum*		Throughout much of SA
Smooth mustard		*Sisymbrium erysimoides*		Throughout much of SA
London rocket		*S. irio*		Throughout much of SA
Wild mustard		*S. orientale*		Throughout much of SA

Table I.3 Introduced plant species of major concern in the region and northern South Australia, including proclaimed species[1] (continued)

Common name	Family	Species name	Classification in SA	Distribution/Concern
Common storks bill	Geraniaceae	*Erodium cicutarium*		Ubiquitous distribution in SA
Buffel grass	Gramineae (Poaceae)	*Cenchrus ciliaris*	Environmental weed (northern Australia)	Mid-northern parts of SA; alters fire-regimes; wildlife management implications
Pitted lovegrass		*Eragrostis barrelieri*		Widespread in the pastoral zone and eastern SA
Annual ryegrass		*Lolium rigidum*		Ubiquitous distribution in southern SA; uncommon/rare in northern pastoral areas
Kikuyu grass		*Pennisetum clandestinum*	Environmental weed; SA Category 3—potential threat	
Tiny bristle-grass		*Rostraria pumila*		Widespread in the pastoral zone and southern SA
Arabian grass		*Schismus barbatus*		Throughout much of SA
Horehound	Labiatae (Lamiaceae)	*Marrubium vulgare*	SA Class 3 noxious weed	
Mesquite	Leguminosae	*Prosopis juliflora*	SA Class 1 noxious weed	Few records from pastoral areas of SA and apparently not spreading in Woomera–Marree areas
Rosy dock	Polygonaceae	*Acetosa vesicaria*		Spread outwards from Oodnadatta Track; widespread; deliberately spread for stock fodder
Three-corner jack		*Emex australis*	SA Class 2 noxious weed; environmental weed; SA Category 1—very serious threat	
African boxthorn	Solanaceae	*Lycium ferocissimum*	SA Class 2 noxious weed; environmental weed; SA Category 1—very serious threat	Not generally distributed north of Port Augusta
Athel pine	Tamaricaceae	*Tamarix aphylla*	NT Class B & C noxious weed; environmental weed (northern South Australia)	Northern SA; displaces native flora, destroying resources for fauna
Caltrop	Zygophyllaceae	*Tribulus terrestris*	SA Class 2 noxious weed	Throughout much of SA

1 *Nomenclature:* Animal and Plant Control (Agricultural and Other Purposes) Act 1986 *(SA).*
Source: Badman 1995; Parsons and Cuthbertson 1992; Humphries et al. 1991.

Table I.4 Introduced plant species recorded for the region and the Project Area

Common name	Family	Species name
Common iceplant	Aizoaceae	*Mesembryanthemum crystallinum*
Salvation jane (Patersons curse)	Boraginaceae	*Echium plantagineum*
Smooth heliotrope		*Heliotropium curassavicum*
Potato weed		*H. europaeum*
Drooping prickly-pear	Cactaceae	*Opuntia vulgaris*
Common pearlwort	Caryophyllaceae	*Sagina apetala*
Lesser sand-spurrey		*Spergularia diandra*
Fat hen	Chenopodiaceae	*Chenopodium album*
Capeweed	Compositae (Asteraceae)	*Arctotheca calendula*
Wild aster		*Aster subulatus*
Flaxleaf fleabane		*Conyza bonariensis*
Gazania		*Gazania linearis*
Sunflower		*Helianthus annuus*
Willow lettuce		*Lactuca saligna*
Prickly lettuce		*L. serriola*
Short-fruited wild turnip		*Rapistrum rugosum*
Prickly sow-thistle		*Sonchus asper* subsp. *glaucescens*
Common sow-thistle		*S. oleraceus*
Clammy sow-thistle		*S. tenerrimus*
Long-fruited wild turnip	Cruciferae (Brassicaceae)	*Brassica tournefortii*
Common bitter cress		*Cardamine hirsuta*
Wards weed		*Carrichtera annua*
Wild mustard		*Sisymbrium orientale*
Paddy melon	Cucurbitaceae	*Citrullus colocynthis*
Bitter melon		*C. lanatus*
Paddy melon		*Cucumis myriocarpus*
Umbrella sedge	Cypercaceae	*Cyperus involucratus*
Spike centaury	Gentianaceae	*Centaurium spicatum*
Crowfoot	Geraniaceae	*Erodium aureum*
Common storks bill		*E. cicutarium*
Wild oat	Gramineae (Poaceae)	*Avena fatua*
Cultivated oat		*A. sativa*
Feathertop Rhodes		*Chloris virgata*
Couch grass		*Cynodon dactylon*
Crab grass		*Digitaria ciliaris*
Barnyard grass		*Echinochloa crus-galli*
Japanese millet		*E. utilis*
Yorkshire fog		*Holcus lanatus*
Barley		*Hordeum vulgare*
Annual ryegrass		*Lolium rigidum*
Paspalum		*Paspalum dilatatum*
Kikuyu grass		*Pennisetum clandestinum*
Canary grass		*Phalaris canariensis*
Winter grass		*Poa annua*
Annual beard-grass		*Polypogon monspeliensis*

Table I.4 Introduced plant species recorded for the region and the Project Area (continued)

Common name	Family	Species name
Arabian grass		*Schismus barbatus*
Foxtail millet		*Setaria italica*
Johnson grass		*Sorghum halepense*
		S. x almum
Burr-medic	Leguminosae	*Medicago polymorpha*
Lucerne		*M. sativa*
Suckling clover		*Trifolium dubium*
Onion weed	Liliaceae	*Asphodelus fistulosus*
Notch-leaved sea-lavender	Limoniaceae	*Limonium sinuatum*
Marshmallow	Malvaceae	*Malva parviflora*
Malvastrum		*Malvastrum americanum*
Rosy dock	Polygonaceae	*Acetosa vesicaria*
Wireweed		*Polygonum aviculare*
Tree tobacco	Solanaceae	*Nicotiana glauca*
White-edged nightshade		*Solanum marginatum*
Black-berry nightshade		*S. nigrum*
Trailing verbena	Verbenaceae	*Verbena supina*

Note: Does not include Tamarix aphylla, *which has been used in some amenity plantings.*
Source: Badman 1995; Z. Bowen, WMC, pers. comm., November 1996.

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APPENDIX J

FAUNA

APPENDIX J

FAUNA

This appendix provides supplementary information on the fauna of the region and the Project Area, including mammals, birds, reptiles and introduced species.

J1 MAMMALS

This section provides a brief description of the native and naturalised mammal species known to occur in the Project Area. Table J1 summarises the current status of mammal species in and adjacent to the Project Area relative to previous studies.

Short-beaked echidna

Short-beaked echidna *(Tachyglossus aculeatus)* is rare in the region and the Project Area although common elsewhere in Australia. This species may avoid temperature extremes by sheltering in caves and rock crevices. The spines of the echidna generally protect it from most predators, although it is occasionally attacked and eaten by dingoes.

Giles' planigale

Giles' planigale *(Planigale gilesi)* is locally rare and restricted to cracking clay depressions with Mitchell grass, and sparse low shrubland on gibber tableland. Elsewhere in Australia, this species is locally common in scattered areas of similar habitat and also in sedgeland around swamps across north-eastern South Australia, south-western Queensland, and in northern New South Wales. The Project Area is located towards the south-western extent of its known range.

Fat-tailed dunnart

Fat-tailed dunnart *(Sminthopsis crassicaudata)* is common throughout the Project Area and the surrounding region in all habitats and vegetation communities except stony creek beds. Capture records do not show an obvious seasonal preference; however, juveniles of this species have been recorded in October, indicating early spring breeding. The species has an extensive distribution throughout temperate Australia.

Stripe-faced dunnart

Stripe-faced dunnart *(Sminthopsis macroura)* is common but apparently restricted to dense cane-grass swamps with deep 'crab holes', and cracking clays with relatively close shrub cover on gibber tableland. An individual of this species was recorded during 1990 in cane-grass swamp approximately 2 km north of the Special Mining Lease boundary. Comparable habitat in the Project Area was considered at the time to be too severely degraded by cattle to be suitable for the species; however, Read (1994) confirmed that the species is present within the Special Mining Lease area. This indicates that destocking of the Project Area may have improved the habitat value of the swamps sufficiently to allow the species to re-establish. Sub-adults have been seen in May and juveniles recorded in October, indicating both late summer and early spring breeding. The species has an extensive distribution throughout central Australia.

Table J.1 Mammal species recorded or suspected to be present in the Olympic Dam region and Project Area

Common name	Family	Species name[1]	Recorded in pilot fauna survey (1980)	Additional species suspected in pilot fauna survey (1980)
	TACHYGLOSSIDAE			
Short-beaked echidna		*Tachyglossus aculeatus*		
	DASYURIDAE			
Kultarr		*Antechinomys laniger*		X
Giles' planigale		*Planigale gilesi*		
Narrow-nosed planigale		*P. tenuirostris*[4]		
Fat-tailed dunnart		*Sminthopsis crassicaudata*		X
Stripe-faced dunnart		*S. macroura*		X
	MACROPODIDAE			
Western grey kangaroo		*Macropus fuliginosus*	X	
Euro		*M. robustus*		
Red kangaroo		*M. rufus*	X	
	MOLOSSIDAE			
White-striped freetail-bat		*Nyctinomus australis*		X
Southern freetail-bat		*Mormopterus planiceps*		X
	VESPERTILIONIDAE			
Gould's wattled bat		*Chalinolobus gouldii*		X
Inland forest bat		*Vespadelus baverstocki*	X	
Eastern forest bat		*V. pumilis*		X
Little forest bat		*V. vulturnus*		
Inland broad-nosed bat		*Scotorepens balstoni*		
Little broad-nosed bat		*S. greyii*		X
Lesser long-eared bat		*Nyctophilus geoffroyi*		X
Greater long-eared bat		*N. timoriensis*		X
Yellow-bellied sheathtail-bat		*Saccolaimus flaviventris*		
	MURIDAE			
Forrest's mouse		*Leggadina forresti*		
House mouse[5]		*Mus musculus*	X	
Dusky hopping-mouse		*Notomys fuscus*		X
Plains rat		*Pseudomys australis*		
Bolam's mouse		*P. bolami*		X
Desert mouse		*P. desertor*		
Dingo	CANIDAE	*Canis lupus dingo*	X	X
Fox[5]		*Vulpes vulpes*		
Cat[5]	FELIDAE	*Felis catus*	X	
European rabbit[5]	LEPORIDAE	*Oryctolagus cuniculus*	X	

1 *Nomenclature source: Strahan (1995).*

2 *SANPWS refers to species listed in Schedules 7 and 8 of the* National Parks and Wildlife Act 1972 *(SA).*

3 *IUCN refers to species listed in International Union for Conservation of Nature and Natural Resources (1996).*

4 *Recorded just outside Special Mining Lease area in 1989 and 1993.*

Recorded in Project Area (1982)	Additional species recorded in region (1982)	Potentially in region (1982)	Conservation status in 1996	Comments
				First recorded in 1996; again in 1997
		X	R (SANPWS)[2] DD (IUCN)[3]	
	X			Recorded in Project Area (Read 1994)
		X	E (SANPWS)	Recorded in region (Read 1994)
X				Commonly recorded
	X			Recorded in Project Area (Read 1994)
	X			First recorded in Project Area during December 1990
X				
X				Recorded in September 1988
	X			
				Recorded in 1996; also recorded in borefields region
				Captured in Project Area December 1989 (WMC—Olympic Dam Operations 1990)
				Captured November 1987 in Olympic Dam Village (WMC—Olympic Dam Operations 1988)
	X			
X				Captured during 1988–89 (WMC—Olympic Dam Operations 1989); commonly recorded
			R (SANPWS) NT (IUCN)	Potentially in borefields region (WMC—Olympic Dam Corporation 1996)
	X		R (SANPWS) NT (IUCN)	Recorded near smelter (WMC—Olympic Dam Operations 1994) and borefields (WMC—Olympic Dam Operations 1992b)
X				Exotic pest species
			E (ESP Act)[6] T(IUCN) E(SANPWS)	Potentially in borefields region (WMC—Olympic Dam Corporation 1996)
			V (ESP Act) T (IUCN)	Recorded in borefields region
			R (SANPWS)	Read (1994). Recorded in Project Area during 1987–89 monitoring programme
			R (SANPWS) NT (IUCN)	Recorded just north of ODO lease in 1990 and January 1993 and 1994 in ODO lease and in borefields region
X	X			Naturalised species
				Introduced species
X				Introduced species
X				Introduced species

5 *Introduced species.*

6 *ESP Act refers to species listed in Schedules to the* Endangered Species Protection Act 1992 *(Cwlth).*

Source: Modified from Read (1994).

DD = Data deficient.
E = Endangered.
NT = Near threatened.
R = Rare.
T = Threatened.
V = Vulnerable.

Western grey kangaroo

Western grey kangaroo *(Macropus fuliginosus)* is abundant in the south-central and south-western portion of Australia. While the population of the species in the Project Area is small, its conservation status in the Project Area and the sheep-grazing pastoral zone of South Australia generally is secure.

Euro

Euro *(Macropus robustus)* is locally common in the region but generally restricted to escarpments and low hills. No such habitat is located in the Project Area; however, an individual of this species was recorded in the Project Area for the first time in December 1990 (WMC—Olympic Dam Operations 1991) and occasional observations are also made in the Project Area. Elsewhere in Australia, the species varies from common to abundant in suitable rocky habitats (Kinhill – Stearns Roger 1982).

Red kangaroo

Red kangaroo *(Macropus rufus)* is common in all woodland, shrubland and grassland habitats throughout the Project Area and surrounding region. Young animals of all ages have been observed in autumn and spring, indicating continuous breeding in favourable conditions. An increase in numbers of this species in the Project Area north of Whenan Shaft has been reported, and appears to be a project-induced modification following the establishment of a source of fresh water for fauna in the region in August 1990. Reliable supplies of fresh water have artificially elevated population numbers in the region and on Roxby Downs Station. Elsewhere the species varies from common to abundant throughout the arid interior, with numbers varying widely in response to seasonal conditions.

Lesser long-eared bat

Lesser long-eared bat *(Nyctophilus geoffroyi)* is common in the Project Area during spring and summer; however, it shows seasonal preference (not recorded in autumn) and appears restricted to sheltered, well-timbered locations. Elsewhere in Australia, the species is common in many areas and most habitats throughout the continent, with the exception of far northern Australia. Individuals of this species normally roost in hollow trees or under bark in groups of up to five. Larger numbers roost in caves or buildings.

Inland broad-nosed bat

Inland broad-nosed bat *(Scotorepens balstoni)* is common throughout the arid zone of all Australian mainland states and has no reported habitat preferences. This species was first recorded in the Project Area in November 1987 (one individual).

Inland forest bat

Inland forest bat *(Vespadelus baverstocki)* is widely distributed throughout Central Australia and is common in the borefields region. It has been recorded once in the Project Area but is likely to be present in larger numbers.

White-striped freetail-bat

White-striped freetail-bat *(Nyctinomus australis)* is common over all woodland habitats, especially myall woodland and mulga scrub, throughout the surrounding region and the Project Area. The species appears to be restricted to areas where there are permanent water sources and an abundance of hollow trees (Reardon 1995). The species shows strong seasonal patterns, with many calls recorded only between April to July (WMC—Olympic Dam Operations 1989). It is probable that the species leaves the region during the hotter months.

Forrest's mouse

Forrest's mouse *(Leggadina forresti)* is restricted to habitats of tussock grasslands and low chenopod shrublands on plains (often of cracking clays) in the region and throughout inland Australia. The species is classified by the International Union for Conservation of Nature and Natural Resources (1996) as rare in South Australia and near-threatened. It has been recorded both in the Project Area (five animals) and just outside the Project Area (thirteen animals).

Bolam's mouse

Bolam's mouse *(Pseudomys bolami)* is distributed throughout the semi-arid areas of southern Western Australia and South Australia. It is usually found in loamy to clay soils in sparse mallee or Acacia woodland with scattered low shrubs.

In South Australia, it is predominantly spring breeding (Strahan 1995). Seventeen individuals of this species were first captured in 1987 in or adjacent to gibber and saltbush habitats (WMC—Olympic Dam Operations 1988). The presence of the species is stable in the Project Area, although numbers vary with seasonal conditions; for example, the species was reported to be thriving in 1990 following particularly heavy rains in 1989 (WMC—Olympic Dam Corporation 1990). Drier conditions in 1995 resulted in lower capture rates (WMC—Olympic Dam Corporation 1996).

Desert mouse

Desert mouse *(Pseudomys desertor)* is classified by the International Union for Conservation of Nature and Natural Resources (1996) as rare in South Australia and near-threatened; however, recent field studies indicate that it is more widespread than previously believed throughout the north-west of South Australia in samphire, sedge and Triodia grassland, and nitrebush habitats (Read et al. In prep.).

Desert mouse has an apparently high tolerance to disturbance factors such as grazing. Capture of individuals of this species in the Project Area in 1993 was unexpected, as the species had not been recorded in South Australia for nineteen years. Its capture at Olympic Dam represented a range extension of 200 km (Read 1994). The species has been recorded twice inside the Project Area and twice in the region immediately adjacent to the Project Area.

Dingo

Dingo *(Canis lupus dingo)* is a naturalised species and is common throughout the arid zone of Australia; however, its southerly migration is restricted by the Dog Fence to the north of the Project Area. Individual dingoes—up to a few animals—are recorded annually in the Project Area and on Roxby Downs and Andamooka stations. To protect the sheep-grazing activities of the region, dingoes detected south of the Dog Fence are declared vermin under the *Dog Fence Act 1946* (SA).

J2 BIRDS

Bird species recorded for a range of sites are listed in the following tables in this section:

- Table J.2, Project Area and adjacent region;
- Table J.3, the Arcoona Lakes region; that is, in the vicinity of the 275 kV transmission line corridor and adjacent areas.

Table J.2 Bird species recorded in the Project Area and adjacent region, 1980–96

Common name	Family	Species name[1]	Species status
Emu	CASUARIIDAE	*Dromaius novaehollandiae*	N/Re
Australasian grebe	PODICIPEDIDAE	*Tachybaptus novaehollandiae*	N/Re
Hoary-headed grebe		*Poliocephalus poliocephalus*	N/Re
Great crested grebe		*Podiceps cristatus*	N/Va
Little pied cormorant	PHALACROCORACIDAE	*Phalacrocorax melanoleucos*	N
Pied cormorant		*P. varius*	N
Little black cormorant		*P. sulcirostris*	N
Great cormorant		*P. carbo*	N
Darter	ANHINGIDAE	*Anhinga melanogaster*	N
Australian pelican	PELECANIDAE	*Pelecanus conspicillatus*	N
Blue-billed duck	ANATIDAE	*Oxyura australis*	N
Musk duck		*Biziura lobata*	N
Freckled duck		*Stictonetta naevosa*	N
Black swan		*Cygnus atratus*	N
Australian shelduck		*Tadorna tadornoides*	N
Wood duck		*Chenonetta jubata*	N
Pacific black duck		*Anas superciliosa*	N
Australasian shoveler		*A. rhynchotis*	N
Grey teal		*A. gracilis*	N
Chestnut teal		*A. castanea*	N
Pink-eared duck		*Malacorhynchus membranaceus*	N
Hardhead		*Aythya australis*	N
Pacific heron	ARDEIDAE	*Ardea pacifica*	N
White-faced heron		*A. novaehollandiae*	N
Little egret		*A. garzetta*	N
Great egret		*A. alba*	N
Intermediate egret		*A. intermedia*	N
Cattle egret		*A. ibis*	N/Va
Nankeen night heron		*Nycticorax caledonicus*	N/Va
Glossy ibis	THRESKIORNITHIDAE	*Plegadis falcinellus*	N
Sacred ibis		*Threskiornis molucca*	N
Straw-necked ibis		*T. spinicollis*	N
Yellow-billed spoonbill		*Platalea flavipes*	N
Black-shouldered kite	ACCIPITRIDAE	*Elanus axillaris*	N
Black-breasted buzzard		*Hamirostra melanosternon*	N
Black kite		*Milvus migrans*	S/Re
Whistling kite		*Haliastur sphenurus*	Re
Spotted harrier		*Circus assimilis*	N
Swamp harrier		*C. approximans*	N
Brown goshawk		*Accipiter fasciatus*	N
Collared sparrowhawk		*A. cirrhocephalus*	N
Wedge-tailed eagle		*Aquila audax*	Re
Little eagle		*Hieraaetus morphnoides*	Re
Brown falcon	FALCONIDAE	*Falco berigora*	Re
Australian hobby		*F. longipennis*	N
Black falcon		*F. subniger*	N
Peregrine falcon		*F. peregrinus*	Va
Nankeen kestrel		*F. cenchroides*	Re

Table J.2 Bird species recorded in the Project Area and adjacent region, 1980–96 (continued)

Common name	Family	Species name[1]	Species status
Stubble quail	PHASIANIDAE	*Coturnix pectoralis*	N
Little button-quail	TURNICIDAE	*Turnix velox*	N
Buff-banded rail	RALLIDAE	*Gallirallus philippensis*	N
Baillon's crake		*Porzana pusilla*	N/Va
Australian spotted crake		*P. fluminea*	N
Purple swamphen		*Porphyrio porphyrio*	N
Dusky moorhen		*Gallinula tenebrosa*	N
Black-tailed native-hen		*G. ventralis*	N
Eurasian coot		*Fulica atra*	N
Australian bustard	OTIDIDAE	*Ardeotis australis*	N
Brolga	GRUIDAE	*Grus rubicunda*	Va
Plains-wanderer	PEDIONOMIDAE	*Pedionomus torquatus*	Va
Black-winged stilt	RECURVIROSTRIDAE	*Himantopus himantopus*	N/Re
Banded stilt		*Cladorhynchus leucocephalus*	N
Red-necked avocet		*Recurvirostra novaehollandiae*	N
Oriental pratincole	GLAREOLIDAE	*Glareola maldivarum*	S/Va
Australian pratincole		*Stiltia isabella*	S/Va
Grey plover	CHARADRIIDAE	*Pluvialis squatarola*	S/Va
Red-capped dotterel		*Charadrius ruficapillus*	N
Inland dotterel		*C. australis*	N/S
Black-fronted dotterel		*Elseyornis melanops*	S/Re
Red-kneed dotterel		*Erythrogonys cinctus*	N
Banded plover		*Vanellus tricolor*	N
Masked plover		*V. miles*	Re
Latham's snipe	SCOLOPACIDAE	*Gallinago hardwickii*	S/Va
Black-tailed godwit		*Limosa limosa*	S/Va
Eastern curlew		*Numenius madagascariensis*	S/Va
Marsh sandpiper		*Tringa stagnatilis*	S
Greenshank		*T. nebularia*	S/Re
Wood sandpiper		*T. glareola*	S
Common sandpiper		*Actitis hypoleucos*	S
Ruddy turnstone		*Arenaria interpres*	S/Va
Red-necked stint		*Calidris ruficollis*	S
Sharp-tailed sandpiper		*C. acuminata*	S
Curlew sandpiper		*C. ferruginea*	S
Silver gull	LARIDAE	*Larus novaehollandiae*	N/Re
Gull-billed tern		*Sterna nilotica*	N
Caspian tern		*S. caspia*	N
Whiskered tern		*Chlidonias hybridus*	N
Feral pigeon	COLUMBIDAE	*Columba livia*[2]	N
Spotted turtle-dove		*Streptopelia chinensis*[2]	Er
Common bronzewing		*Phaps chalcoptera*	N
Flock bronzewing		*P. histrionica*	N/Va
Crested pigeon		*Ocyphaps lophotes*	Re
Diamond dove		*Geopelia cuneata*	N
Peaceful dove		*G. striata*	N

Table J.2 Bird species recorded in the Project Area and adjacent region, 1980–96 (continued)

Common name	Family	Species name[1]	Species status
Galah	CACATUIDAE	*Cacatua roseicapilla*	Re
Little corella		*C. sanguinea*	Re
Major Mitchell		*C. leadbeateri*	N
Cockatiel		*Nymphicus hollandicus*	N
Blue bonnet	PSITTACIDAE	*Northiella haematogaster*	Re
Mulga parrot		*Psephotus varius*	N
Budgerigar		*Melopsittacus undulatus*	N
Bourke's parrot		*Neopsephotus bourkii*	Re
Blue-winged parrot		*Neophema chrysostoma*	N/S
Oriental cuckoo	CUCULIDAE	*Cuculus saturatus*	N/S
Pallid cuckoo		*C. pallidus*	N
Black-eared cuckoo		*Chrysococcyx osculans*	N
Horsfield's bronze-cuckoo		*C. basalis*	N
Southern boobook	STRIGIDAE	*Ninox novaeseelandiae*	N
Barn owl		*Tyto alba*	N
Tawny frogmouth	PODARGIDAE	*Podargus strigoides*	Re
Australian owlet-nightjar	AEGOTHELIDAE	*Aegotheles cristatus*	Re
Spotted nightjar	CAPRIMULGIDAE	*Eurostopodus argus*	N
Fork-tailed swift	APODIDAE	*Apus pacificus*	Va
Red-backed kingfisher	HALCYONIDAE	*Todiramphus pyrrhopygia*	S
Rainbow bee-eater	MEROPIDAE	*Merops ornatus*	S
White-backed swallow	HIRUNDINIDAE	*Cheramoeca leucosternus*	Re
Welcome swallow		*Hirundo neoxena*	Re
Tree martin		*H. nigricans*	S
Fairy martin		*H. ariel*	S
Richard's pipit	MOTACILLIDAE	*Anthus novaeseelandiae*	Re
Black-faced cuckoo-shrike	CAMPEPHAGIDAE	*Coracina novaehollandiae*	Re
Ground cuckoo-shrike		*C. maxima*	N
White-winged triller		*Lalage sueurii*	S
Red-capped robin	PETROICIDAE	*Petroica goodenovii*	S
Hooded robin		*Melanodryas cucullata*	Re
Crested bellbird	PACHYCEPHALIDAE	*Oreoica gutturalis*	Re
Rufous whistler		*Pachycephala rufiventris*	S/Va
Grey shrike-thrush		*Colluricincla harmonica*	Re
Restless flycatcher		*Myiagra inquieta*	N
Magpie-lark		*Grallina cyanoleuca*	Re
Grey fantail		*Rhipidura fuliginosa*	N
Willie wagtail		*R. leucophrys*	Re
Chirruping wedgebill	ORTHONYCHIDAE	*Psophodes cristatus*	Re
Cinnamon quail-thrush		*Cinclosoma cinnamomeum*	Re
White-browed babbler	POMATOSTOMIDAE	*Pomatostomus superciliosus*	Re
Clamorous reed-warbler	SYLVIIDAE	*Acrocephalus stentoreus*	N/Re
Little grassbird		*Megalurus gramineus*	N/Re
Rufous songlark		*Cincloramphus mathewsi*	N
Brown songlark		*C. cruralis*	N

Table J.2 Bird species recorded in the Project Area and adjacent region, 1980–96 (continued)

Common name	Family	Species name[1]	Species status
Splendid fairy-wren	MALURIDAE	*Malurus splendens*	Re
Variegated fairy-wren		*M. lamberti*	Re
White-winged fairy-wren		*M. leucopterus*	Re
Thick-billed grasswren		*Amytornis textilis modestus*	P
Varied sittella	NEOSITTIDAE	*Daphoenositta chrysoptera*	N
Spiny-cheeked honeyeater	MELIPHAGIDAE	*Acanthagenys rufogularis*	Re
Yellow-throated miner		*Manorina flavigula*	Re
Singing honeyeater		*Lichenostomus virescens*	Re
Grey-fronted honeyeater		*L. plumulus*	Va
White-plumed honeyeater		*L. penicillatus*	Re
White-fronted honeyeater		*Phylidonyris albifrons*	N
Pied honeyeater		*Certhionyx variegatus*	N
Crimson chat	EPHTHIANURIDAE	*Epthianura tricolor*	N
Orange chat		*E. aurifrons*	N
White-fronted chat		*E. albifrons*	N
Gibberbird		*Ashbyia lovensis*	N
Mistletoebird	DICAEIDAE	*Dicaeum hirundinaceum*	N/S
Red-browed pardalote	PARDALOTIDAE	*Pardalotus rubricatus*	N
Striated pardalote		*P. striatus*	N/S
Striated fieldwren		*Calamanthus fuliginosus*	Re
Western fieldwren		*C. campestris*	Re
Inland thornbill		*Acanthiza apicalis*	Re
Chestnut-rumped thornbill		*A. uropygialis*	Re
Yellow-rumped thornbill		*A. chrysorrhoa*	N
Southern whiteface		*Aphelocephala leucopsis*	Re
House sparrow	PLOCEIDAE	*Passer domesticus*[2]	Re
Zebra finch		*Taeniopygia guttata*	Re
Starling	STURNIDAE	*Sturnus vulgaris*[2]	N/Re
White-breasted woodswallow	ARTAMIDAE	*Artamus leucorynchus*	Re
Masked woodswallow		*A. personatus*	N
White-browed woodswallow	*A. superciliosus*	N	
Black-faced woodswallow		*A. cinereus*	Re
Grey butcherbird		*Cracticus torquatus*	Re
Australian magpie		*Gymnorhina tibicen*	Re
Australian raven	CORVIDAE	*Corvus coronoides*	Re
Little crow		*C. bennetti*	Re

1 *Christidis and Boles 1994.*
2 *Introduced species.*
Er Eradicated (an introduced species that has been removed).
N Nomadic (long-distance movements).
P Presence has been recorded; however, resident outside region.
Re Resident (may move small distances locally).
S Seasonal visitor.
Va Vagrant (outside normal recognised range).
Sources: Read 1994; WMC—Olympic Dam Corporation 1996; WMC—Olympic Dam Operations 1993, 1994, 1995 and WMC—Olympic Dam Corporation 1996.

Table J.3 Bird species recorded in the Arcoona Lakes region[1]

Common name	Family and species name[2]	Purple Lake	Coorlay Lagoon	Lake Mary	Lake Richardson
	CASUARIIDAE				
Emu	*Dromaius novaehollandiae*	X	X		X
	PODICIPEDIDAE				
Australasian grebe	*Tachybaptus novaehollandiae*	X	X	X	X
Hoary-headed grebe	*Poliocephalus poliocephalus*	X	X	X	X
Great crested grebe	*Podiceps cristatus*		X	X	X
	PHALACROCORACIDAE				
Little pied cormorant	*Phalacrocorax melanoleucos*	X	X	X	X
Pied cormorant	*P. varius*		X		X
Little black cormorant	*P. sulcirostris*	X	X		X
Great cormorant	*P. carbo*		X	X	X
	ANHINGIDAE				
Darter	*Anhinga melanogaster*		X		X
	PELECANIDAE				
Australian pelican	*Pelecanus conspicillatus*		X		X
	ANATIDAE				
Blue-billed duck	*Oxyura australis*		X	X	
Musk duck	*Biziura lobata*	X	X		X
Freckled duck	*Stictonetta naevosa*	X	X	X	X
Black swan	*Cygnus atratus*	X	X	X	X
Australian shelduck	*Tadorna tadornoides*	X		X	
Wood duck	*Chenonetta jubata*	X	X	X	X
Pacific black duck	*Anas superciliosa*	X	X	X	X
Australasian shoveler	*A. rhynchotis*	X	X	X	X
Grey teal	*A. gracilis*	X	X	X	X
Chestnut teal	*A. castanea*	X	X	X	X
Pink-eared duck	*Malacorhynchus membranaceus*	X	X	X	X
Hardhead	*Aythya australis*	X	X	X	X
	ARDEIDAE				
Pacific heron	*Ardea pacifica*		X		
White-faced heron	*A. novaehollandiae*	X	X	X	X
Little egret	*A. garzetta*		X	X	
Great egret	*A. alba*		X		
Nankeen night heron	*Nycticorax caledonicus*			X	X
	THRESKIORNITHIDAE				
Glossy ibis	*Plegadis falcinellus*	X	X	X	
Sacred ibis	*Threskiornis molucca*		X	X	
Straw-necked ibis	*T. spinicollis*		X		
Yellow-billed spoonbill	*Platalea flavipes*	X	X		X
	ACCIPITRIDAE				
Black kite	*Milvus migrans*	X	X	X	X
Whistling kite	*Haliastur sphenurus*		X	X	X
Collared sparrowhawk	*Accipiter cirrhocephalus*	X			
Wedge-tailed eagle	*Aquila audax*	X	X	X	X
Little eagle	*Hieraaetus morphnoides*			X	

Table J.3 Bird species recorded in the Arcoona Lakes region[1] (continued)

Common name	Family and species name[2]	Purple Lake	Coorlay Lagoon	Lake Mary	Lake Richardson
	FALCONIDAE				
Australian hobby	*Falco longipennis*	X	X		X
Nankeen kestrel	*F. cenchroides*	X	X		X
	PHASIANIDAE				
Stubble quail	*Coturnix pectoralis*		X		
	RALLIDAE				
Black-tailed native-hen	*Gallinula ventralis*	X	X	X	X
Eurasian coot	*Fulica atra*	X	X	X	X
	RECURVIROSTRIDAE				
Black-winged stilt	*Himantopus himantopus*	X	X	X	X
Banded stilt	*Cladorhynchus leucocephalus*	X	X	X	X
Red-necked avocet	*Recurvirostra novaehollandiae*	X	X	X	X
	GLAREOLIDAE				
Australian pratincole	*Stiltia isabella*	X			
	CHARADRIIDAE				
Grey plover	*Pluvialis squatarola*		X		X
Red-capped dotterel	*Charadrius ruficapillus*	X	X	X	X
Black-fronted dotterel	*Elseyornis melanops*	X	X	X	X
Red-kneed dotterel	*Erythrogonys cinctus*	X	X	X	X
Banded plover	*Vanellus tricolor*	X	X	X	X
Masked plover	*V. miles*	X	X	X	X
	SCOLOPACIDAE				
Black-tailed godwit	*Limosa limosa*	X	X		
Marsh sandpiper	*Tringa stagnatilis*	X	X	X	
Greenshank	*T. nebularia*	X	X	X	X
Wood sandpiper	*T. glareola*	X	X	X	
Common sandpiper	*Actitis hypoleucos*	X	X		
Ruddy turnstone	*Arenaris interpres*		X		
Eastern curlew	*Numenius madagascariensis*		X		
Red-necked stint	*Calidris ruficollis*	X	X	X	X
Sharp-tailed sandpiper	*C. acuminata*	X	X	X	X
Curlew sandpiper	*C. ferruginea*	X	X	X	X
	LARIDAE				
Silver gull	*Larus novaehollandiae*	X	X	X	X
Gull-billed tern	*Sterna nilotica*	X	X	X	X
Caspian tern	*S. caspia*		X	X	X
Whiskered tern	*Chlidonias hybridus*	X	X	X	X
	COLUMBIDAE				
Common bronzewing	*Phaps chalcoptera*			X	
Crested pigeon	*Ocyphaps lophotes*	X	X		X
Diamond dove	*Geopelia cuneata*	X	X		X
	CACATUIDAE				
Galah	*Cacatua roseicapilla*	X	X	X	
Little corella	*C. sanguinea*	X	X	X	
Cockatiel	*Nymphicus hollandicus*	X	X	X	X
	PSITTACIDAE				
Blue bonnet	*Northiella haematogaster*	X			X

Table J.3 Bird species recorded in the Arcoona Lakes region[1] (continued)

Common name	Family and species name[2]	Purple Lake	Coorlay Lagoon	Lake Mary	Lake Richardson
Mulga parrot	*Psephotus varius*				X
Budgerigah	*Melopsittacus undulatus*	X	X	X	X
	CUCULIDAE				
Pallid cuckoo	*Cuculus pallidus*	X	X		
Horsfield's bronze-cuckoo	*Chrysococcyx basalis*		X		
	MEROPIDAE				
Rainbow bee-eater	*Merops ornatus*		X		
	HIRUNDINIDAE				
Welcome swallow	*Hirundo neoxena*	X	X		
Tree martin	*H. nigricans*	X	X		
Fairy martin	*H. ariel*	X	X		
	MOTACILLIDAE				
Richard's pipit	*Anthus novaeseelandiae*	X	X		X
	CAMPEPHAGIDAE				
Black-faced cuckooshrike	*Coracina novaehollandiae*				X
	PETROICIDAE				
Red-capped robin	*Petroica goodenovii*			X	
	PACHYCEPHALIDAE				
Magpie-lark	*Grallina cyanoleuca*	X	X	X	X
Grey fantail	*Rhipidura fuliginosa*			X	X
Willie wagtail	*Rhipidura leucophrys*	X	X		X
	SYLVIIDAE				
Brown songlark	*Cincloramphus cruralis*	X			
	EPTHIANURIDAE				
Orange chat	*Epthianura aurifrons*	X	X		X
White-fronted chat	*E. albifrons*		X		X
	PARDALOTIDAE				
Chestnut-rumped thornbill	*Acanthiza uropygialis*	X	X	X	X
Yellow-rumped thornbill	*A. chrysorrhoa*	X		X	X
	PLOCEIDAE				
Zebra finch	*Taeniopygia guttata*	X	X	X	X
	STURNIDAE				
Starling	*Sturnus vulgaris*[3]	X	X		
	ARTAMIDAE				
White-breasted woodswallow	*Artamus leucorynchus*	X			
Black-faced woodswallow	*Artamus cinereus*	X	X		X
Grey butcherbird	*Cracticus torquatus*	X	X	X	X
Australian magpie	*Gymnorhina tibicen*	X	X	X	X
	CORVIDAE				
Australian raven	*Corvus coronoides*	X	X		X
Little crow	*C. bennetti*	X	X		X

1 *Adjacent to the power transmission line corridor and south of the Project Area.*
2 *Christidis and Boles 1994.*
3 *Introduced species.*
Source: WMC—Olympic Dam Operations (1992a); Read and Ebdon (In prep.).

J3 REPTILES

Table J.4 summarises the current status of reptile species in and adjacent to the Project Area relative to previous studies and Table J.5 presents additional species that could be expected to occur in the Project Area.

Table J.4 Reptile species recorded in the Project Area and region

Common name	Family and species name[1]	Recorded in pilot fauna survey (1980)	Recorded in Project Area (1982)	Recorded in Project Area (to 1997)	Species recorded in region
	GEKKONIDAE				
Spiny-tailed gecko	*Diplodactylus ciliaris*	X	X	X	X
Fat-tailed diplodactylus	*D. conspicillatus*		X	X	
Beaded gecko	*D. damaeus*[2]	X	X	X	X
	D. stenodactylus		X	X	X
Tessellated gecko	*D. tessellatus*		X	X	X
Tree dtella	*Gehyra variegata*	X	X	X	X
	G. purpurascens				X
Bynoe's gecko	*Heteronotia binoei*			X	X
Beaded gecko	*Lucasium damaeum*			X	X
Knob-tailed gecko	*Nephrurus levis*		X	X	X
Beaked gecko	*Rhynochoedura ornata*		X	X	X
Thick-tailed gecko	*Underwoodisaurus milii*			X	X
	PYGOPODIDAE				
Hooded scaly-foot	Pygopodus nigriceps		X	X	X
	VARANIDAE				
Pygmy mulga monitor	*Varanus gilleni*		X		X
Gould's goanna	*V. gouldii*			X	X
	AGAMIDAE				
Mallee dragon	*Ctenophorus fordi*			X	X
Central netted dragon	*C. nuchalis*		X	X	X
Painted dragon	*C. pictus*		X	X	X
	Pogona vitticeps	X	X	X	X
	Tympanocryptis intima		X	X	X
	T. lineata		X	X	X
	T. tetraporophora				X
	SCINCIDAE				
	Cryptoblepharus plagiocephalus (formerly *C. boutonii*)				X
	Ctenotus brooksi		X	X	X
	C. leae			X	X
	C. leonhardii		X	X	
	C. regius		X	X	X
	C. schomburgkii		X	X	
	C. strauchii		X	X	
	C. uber			X	X
	Egernia stokesii				X
Desert banded skink	*Eremiascincus richardsonii*		X	X	X
	Lerista desertorum			X	X
	L. labialis		X	X	X

Table J.4 Reptile species recorded in the Project Area and region (continued)

Common name	Family and species name[1]	Recorded in pilot fauna survey (1980)	Recorded in Project Area (1982)	Recorded in Project Area (to 1997)	Species recorded in region
	L. muelleri			X	
	Menetia greyii		X	X	X
	Morethia adelaidensis		X	X	
	M. boulengeri			X	X
Western blue-tongued lizard	*Tiliqua occipitalis*		X	X	X
Shingle back	*Trachydosaurus rugosus*	X	X	X	X
	TYPHLOPIDAE				
Blind snake	*R. bituberculatus*		X	X	
Blind snake	*R. endoterus*		X	X	X
	ELAPIDAE				
Mulga snake	*Pseudechis australis*		X	X	X
Ringed brown snake	*Pseudonaja modesta*		X	X	X
Western brown snake	*P. nuchalis*		X	X	X
Desert banded snake	*Simoselaps bertholdi*		X	X	X
Narrow-banded snake	*S. fasciolatus*		X	X	X
Myall or curl snake	*Suta suta*			X	X
	BOIDAE				
Woma python	*Aspidites ramsayi*[3]			X	

1 *Nomenclature: Unless otherwise stated, Cogger (1992).*
2 *Nomenclature from M. Hutchinson, SA Museum, pers. comm., December 1996.*
3 *Species listed as endangered (International Union for Conservation of Nature and Natural Resources 1996) and rare (Department of Environment and Natural Resources 1993).*
Source: Modified from Read (1994).

Table J.5 Additional reptile species that may be expected to be present within the Project Area and region

Common name	Family and species name[1]	Status
	GEKKONIDAE	
	Diplodacylus byrnei	
Wood gecko	*D. vittatus*	
Beaded gecko	*Lucasium damaeum*	
	PYGOPODIDAE	
	Delma australis	
	D. nasuta	
Burton's snake lizard	*Lialis burtonis*	
Common scaly-foot	*Pygopodus lepidopodus*	
	Ctenophorus fionni	
Gibber dragon	*C. gibba*	Rare[2]; Vulnerable[3]
Red-barred dragon	*C. vadnappa*	Vulnerable[3]
	Diporiphora winneckei	
	SCINCIDAE	
	Ctenotus robustus	
Narrow banded sand swimmer	*Eremiascinus fasciolatus*	
	Lerista bipes	
	L. bougainvillii	Potentially regionally significant[4]
	L. dorsalis	Potentially regionally significant[4]

Table J.5 Additional reptile species that may be expected to be present within the Project Area and region (continued)

Common name	Family and species name[1]	Status
	L. frosti	
	L. xanthura	
	TYPHLOPIDAE	
	Ramphotyphlops australis	
	ELAPIDAE	
Yellow-faced whip snake	*Demansia psammophis*	
Hooded snake	*S. monachus*	Rare[2]
Bandy-bandy	*Vermicella annulata*	Rare[2]
	BOIDAE	
Stimson's python	*Liasis stimsoni*	Rare[2]

1 *Nomenclature: Unless otherwise stated, Cogger (1992).*
2 *Department of Environment and Natural Resources (1993).*
3 *Kennedy (1990).*
4 *M. Hutchinson, SA Museum, pers. comm., December 1996.*

J4 INTRODUCED VERTEBRATES

The adverse impacts of introduced animals include:

- changes to vegetation community floristics and habitat, including the colonisation of introduced plant species when native vegetation is degraded;
- predation of indigenous animal species;
- competition for food and shelter with indigenous animal species;
- over-grazing of native vegetation;
- removal of native plant seed banks by granivorous pest species;
- introduction and transfer of disease;
- soil erosion where vegetation is heavily grazed;
- increase in food resources for introduced predators.

European rabbit

Within the region, rabbits *(Oryctolagus cuniculus)* are abundant in all areas, particularly following substantial rainfall, when their range increases. Rabbits cause extensive damage to native vegetation and can decimate regenerating and mature vegetation communities. Furthermore, the degradation of native vegetation exposes the land to wind and water erosion (Baker 1992).

Myxomatosis virus now claims less than a 30% mortality rate (Strahan 1995). Consequently, Rabbit Calicivirus Disease, another biological control virus developed for the control of rabbits in Australia and New Zealand, was officially released in South Australia on 22 October 1996.

Based on the low population numbers of rabbits presently in the Project Area, it is suspected that Rabbit Calicivirus Disease has reached rabbit populations in the region.

Cat

On a regional basis, cats *(Felis catus)* are a significant threat to native fauna in the region. The greatest impacts of cats in this region are predation of small mammal, bird and reptile species and competition for resources with small to medium native mammal species. Cats are also a significant predator of rabbits.

House mouse

House mouse *(Mus musculus)* competes with small native animals, particularly granivores, for resources. This species also provides a major food resource both for other introduced pest animals (particularly foxes and cats) and for some indigenous species, including mammals, birds and reptiles.

House mice in the region are present in variable numbers and are dependent on food resources and climatic conditions. The greatest impacts of house mice to the natural environment are direct grazing of the seeds of native vegetation species, particularly grasses, and competition for food and habitat with native mammal species.

Fox

Foxes *(Vulpes vulpes)* are relatively large carnivorous animals that are opportunistic predators and scavengers (Strahan 1995). Records of this animal have shown it to be a predator of some endangered or locally rare species in Australia, including rock-wallabies, brush-tailed bettong and numbat, as well as farm livestock and rabbits (Strahan 1995; Saunders et al. 1995). Predation and competition for resources with the dingo *(Canis lupus dingo)* have reduced the density of foxes north of the Dog Fence (Kemper 1990).

Regionally, it is highly probable that foxes, like cats, prey on a number of mammal, reptile and bird species. A Draft Threat Abatement Plan for the management of foxes has been prepared under the Commonwealth *Endangered Species Protection Act 1992* (Australian Nature Conservation Agency 1996). This plan describes the research and management actions considered necessary for reducing predation of native species by foxes to an acceptable level. The plan also proposes that national control of foxes would be most successful if programmes were established on a regional basis.

Dingo/wild dog

The range of the dingo *(Canis lupus dingo)* in northern South Australia is restricted by the Dog Fence, a dingo-proof and dog-proof fence constructed to protect grazing stock, primarily sheep, from predation by the dingo. The presence of the Dog Fence, and the control of dingoes and dogs *(Canis familiaris)* south of the fence, have meant that dingoes are not present in significant numbers in the region or the Project Area.

Dingoes have long been considered a pest species Australia-wide, particularly as a menace to stock; hence, the erection of the Dog Fence in the late 1800s to mid-1900s. Nowadays, however, dingoes are considered by some (e.g. Corbett 1995; Kemper and Read 1991) to be an integral part of the arid ecosystem. Furthermore, there is a sound argument to reintroduce the dingo to areas of South Australia to reduce the impact of introduced animals, such as the European rabbit, fox and cat (D. Niejalke, WMC, pers. comm., February 1997).

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APPENDIX K

MOUND SPRINGS

APPENDIX

K MOUND SPRINGS

This appendix provides background and supplementary information related to the flora and fauna (vertebrate and invertebrate) of the mound springs.

K1 FLORA

This section contains the following tables and information:

- Table K.1—Number of mound springs assessed during the flora monitoring programme 1983–95;
- Table K.2—Mound spring flora and frequency classification of species;
- Table K.3—Non-vascular vegetation distribution in Wangianna and Marree spring complexes;
- Table K.4—Mound springs flora and conservation significance relative to spring complex and spring group.

Table K.1 Number of mound springs assessed during the flora monitoring programme 1983–95

Spring complex and group	1983	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
COWARD SPRING											
Anna	2			2					3		
Blanche Cup	6	2	2	6	9	9	9	10	10	10	9
Horse East	11		9	9	9	10	9	9	9	9	9
Horse West	7		5	5	3	4	4	4	4	4	4
Mount Hamilton Ruins	1		1	1			1	1	1		1
Buttercup	5		2	4	4	4	4	4	4	4	4
HERMIT HILL											
Bopeechee	14	14	13	13	10	10	11	11	11	11	16
Beatrice	6	4	4	4	4	3	3	3	3	3	3
Dead Boy	8	8	12	9	12	12	12	11	11	11	12
Dead Boy extension											2
Hermit Springs	58	59	81	93	91	90	84	87	85	89	94
Northwest	8			26	3		21		20	5	
Old Finniss	31	25	30	45	49	46	46	47	49	51	62
Old Woman	11	12	14	19	19	19	17	16	15	16	21
Sulphuric	14	13	12	13	18	16	17	17	15	15	19
Venable	6			3	2	3	2	4	2	2	1
West Finniss	45	42	56	54	65	66	66	67	65	65	68
LAKE EYRE											
Emerald	4		3	4	3	3	3	3	3	3	3
Fred East	8	8	13	11	11	11	9	9	9	9	9
Fred West	4	2	3	3	5	5	5	5	5	5	4
Gosse	9	4	9	8	8	8	9	9	9	9	10
Jacobs	3	2	2	3	2	2	2	2	2	2	2
MacLachlan	11	2	5	4	2	4	5	6	12	7	6

Table K.1 Number of mound springs assessed during the flora monitoring programme 1983–95 (continued)

Spring complex and group	1983	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Priscilla	6	4	4	4	4	4	4	3	3		3
Smith	15		6	10	10	10	10	10	10	10	14
MARREE											
Marree (Hergott)											5
WANGIANNA											
Davenport	16	16	11	13	13	12	12	12	12	13	13
Wangianna	1										2
Welcome											23
Year total	**310**	**217**	**297**	**366**	**356**	**351**	**365**	**350**	**372**	**353**	**419**

Table K.2 Flora recorded in association with mound springs and frequency classification of species recorded during the flora monitoring programme

Common name	Family	Species	Status
Green pigface	Aizoaceae	*Gunniopsis septifraga*	uncommon[1]
		Tetragonia eremaea	uncommon[1]
Red spinach		*Trianthema triquetra*	uncommon
Large-flowered amaranth	Amaranthaceae	*Amaranthus grandiflorus*	very uncommon[1]
Sand-spurrey	Caryophyllaceae	*Spergularia rubra*[2]	common
Gibber saltbush	Chenopodiaceae	*Atriplex fissivalvis*	uncommon
Pop saltbush		*A. holocarpa*	status not recorded
Baldoo		*A. lindleyi*	uncommon[1]
Old-man saltbush		*A. nummularia*	common
Pop saltbush		*A. spongiosa*	common
Sandhill saltbush		*A. velutinella*	uncommon
Fat hen		*Chenopodium album*[2]	very uncommon[1]
Ball bindyi		*Dissocarpus paradoxus*	uncommon
Ruby saltbush		*Enchylaena tomentosa* subsp. *tomentosa*	common
Grey samphire		*Halosarcia halocnemoides*	very uncommon[1]
Cottonbush		*Maireana aphylla*	uncommon
Bluebush		*M. appressa*	common
Fissure-weed		*M. ciliata*	very uncommon
Rosy bluebush		*M. erioclada*	very uncommon
Soda bush		*Neobassia proceriflora*	very uncommon[1]
Water weed		*Osteocarpum acropterum*	uncommon
Buckbush		*Salsola kali*	uncommon[1]
Short-winged copperburr		*Sclerolaena brachyptera*	uncommon[1]
Green copperburr		*S. decurrens*	uncommon
Grey copperburr		*S. diacantha*	uncommon
Poverty-bush		*S. divaricata*	very uncommon[1]
Woolly copperburr		*S. lanicuspis*	very uncommon
Limestone copperburr		*S. obliquicuspis*	very uncommon
Salt copperburr		*S. ventricosa*	uncommon

Table K.2 Flora recorded in association with mound springs and frequency classification of species recorded during the flora monitoring programme (continued)

Common name	Family	Species	Status
	Compositae (Asteraceae)	*Calocephalus* sp. aff. *platycephalus*	uncommon[1]
Slender sunray		*Rhodanthe stricta*	uncommon[1]
Minnie daisy		*Minuria leptophylla*	uncommon[1]
Apple-bush		*Pterocaulon sphacelatum*	uncommon
Groundsel		*Senecio glossanthus*	uncommon[1]
Fleshy groundsel		*Orthonna gregorii*	very uncommon[1]
Common sowthistle		*Sonchus oleraceus*[2]	uncommon[1]
Long-fruited wild turnip	Cruciferae (Brassicaceae)	*Brassica tournefortii*[2]	uncommon[1]
Veined peppercress		*Lepidium phlebopetalum*	uncommon[1]
Paddy melon	Cucurbitaceae	*Citrullus colocynthis*[2]	very uncommon[1]
Bare twig-rush	Cyperaceae	*Baumea juncea*	abundant[3]; biogeographically significant
Bore-drain sedge		*Cyperus laevigatus*	abundant
Spiny flat-sedge		*C. gymnocaulos*	uncommon
Common fringe-rush		*Fimbristylis dichotoma*	abundant[3]
Cutting grass		*Gahnia trifida*	abundant[3]; biogeographically significant
Club-rush		*Schoenoplectus litoralis*	uncommon; biogeographically significant
American club-rush		*S. pungens*	very uncommon
Salt pipewort	Eriocaulaceae	*Eriocaulon carsonii*	abundant[3]; endangered
Common storks bill	Geraniaceae	*Erodium cicutarium*[2]	very uncommon[1]
Dune fanflower	Goodeniaceae	*Scaevola collaris*	uncommon
Button grass	Gramineae (Poaceae)	*Dactyloctenium radulans*	uncommon
Brown beetle-grass		*Diplachne fusca*	common
Mulka grass		*Eragrostis dielsii*	common
Tiny bristle-grass		*Rostraria pumila*[2]	very uncommon[1]
Barbed-wire grass		*Paractaenum novaehollandiae*	very uncommon[1]
Common reed		*Phragmites australis*	abundant
Salt couch		*Sporobolus virginicus*	abundant
Purple heads		*Triraphis mollis*	uncommon[1]
Sandhill cane-grass		*Zygochloa paradoxa*	uncommon
Sea rush	Juncaceae	*Juncus kraussii*	common[3]; special significance
Redflower lotus	Leguminosae	*Lotus cruentus*	very uncommon[1]
		Swainsona ?oligophylla	very uncommon[1]
Sweet fenugreek		*Trigonella suavissima*	uncommon[1]
Umbrella bush		*Acacia ligulata*	uncommon
Native willow		*A. salicina*	common
Australian hollyhock	Malvaceae	*Lavatera plebeia*	very uncommon[1]
Clustered lawrencia		*Lawrencia glomerata*	very uncommon[1]
	Myoporaceae	*Myoporum acuminatum*	common
		M. brevipes	uncommon
Native myrtle		*M. montanum*	uncommon[1]

Table K.2 Flora recorded in association with mound springs and frequency classification of species recorded during the flora monitoring programme (continued)

Common name	Family	Species	Status
Sago weed	Plantaginaceae	*Plantago drummondii*	very uncommon[1]
Bristly dock	Polygonaceae	*Rumex crystallinus*	very uncommon[1]
Pondweed	Potamogetonaceae	*Potamogeton pectinatus*	uncommon
Creeping brookweed	Primulaceae	*Samolus repens*	uncommon
Velvet tobacco	Solanaceae	*Nicotiana velutina*	uncommon
Athel pine	Tamaricaceae	*Tamarix aphylla*[2]	uncommon
Desert riceflower	Thymelaeaceae	*Pimelea simplex*	very uncommon[1]
Cumbungi	Typhaceae	*Typha domingensis*	common
Cumbungi		*T. orientalis*	status not recorded
Native carrot	Umbelliferae (Apiaceae)	*Daucus glochidiatus*	uncommon[1]
Nitrebush	Zygophyllaceae	*Nitraria billardierei*	common
Sand twinleaf		*Zygophyllum ammophilum*	uncommon[1]
Clasping twinleaf		*Z. howittii*	very uncommon
Square-fruit twinleaf		*Z. prismatothecum*	very uncommon[1]

1 Species recorded only following 1989 floods.
2 Introduced species.
3 Species distribution outside mound springs is limited.
Status: Abundant: frequency of occurrence greater that 10% and less than or equal to 100%.
Common: frequency of occurrence greater than 1% and less than or equal to 10%.
Uncommon: frequency of occurrence greater than 0.1% and less than or equal to 1%.
Very uncommon: frequency of occurrence greater than 0.01% and less than or equal to 0.1%.
Frequency classification based on 2,251 sampling units (Fatchen and Fatchen 1993).

Table K.3 Non-vascular vegetation distribution in Wangianna and Marree spring complexes

Spring	Algae			Diatoms		Non-photosynthetic protozoans	**Total**
	Red	Green	Blue-green	Pennate	Centric		
WWA001	–	5	3	3	1	1	**13**
WWS001	–	2	1	-	–	–	**3**
WWS002	1	–	2	4	–	1	**8**
WWS002A	–	3	2	4	–	–	**9**
WWS004	–	4	4	4	–	–	**12**
WWS005	–	1	5	3	–	–	**9**
WWS009	–	3	4	3	–	–	**10**
WWS013	–	1	1	2	–	–	**4**
MHE001	–	3	1	4	1	–	**9**
MHE002	–	2	4	5	–	1	**12**
MWI001	1	2	4	1	1	–	**9**
MWI002	–	2	2	2	1	1	**8**

Table K.4 Mound springs flora and conservation significance relative to spring complex and spring group

Spring complex	Bare twigrush (A, L, B)	Spiny flat-sedge (U)	Bore-drain sedge (A)	Salt pipewort (A, L, T)	Common fringe-rush (A, L)	Cutting grass (A, L, B)	Sea rush (C, L, S)	Common reed (A)	Salt couch (A)	Cumbungi (C)
LAKE EYRE SUPERGROUP										
BILLA KALINA										
Billa Kalina		X	X				X	X	X	X
COWARD										
Blanche Cup		X	X					X	X	
Buttercup			X					X		
Coward		X	X				X	X		
Elizabeth	X		X				X	X	X	
Elizabeth North	X		X				X	X		
Horse East			X					X		
Horse West			X					X		
Jersey			X					X		
Kewson Hill			X							
Mount Hamilton Ruins			X							
Strangways		X	X			X	X	X	X	
The Bubbler			X							
HERMIT HILL										
Bopeechee	X		X	X	X			X	X	X
Beatrice			X					X	X	
Dead Boy			X				X	X		
Hermit Springs	X	X	X	X	X	X	X	X	X	
Northwest	X		X	X	X			X	X	
Old Finniss	One record, possible observer error		X	X	X			X	X	
Old Woman		X	X	Transplant, unsuccessful	X	X		X	X	
Sulphuric		X	X	Transplant, successful	X		X	X	X	X
West Finniss	X		X	X	X	X	X	X	X	
Venable			X					X		
LAKE EYRE										
Emerald			X					X		X
Fred East			X					X	X	X
Fred West			X					X		
Gosse			X					X		
Jacobs			X							
McLachlan			X					X		
Priscilla			X							
Smith			X							
FRANCIS SWAMP										
Emily			X							X
Francis Swamp	X	X	X			X	X	X	X	
William		X								X
MOUNT DENISON										
Garnet (north of Freeling)		X	X							X
Sandy Creek		X						X	X	
Wilparoona		X				X				X

Table K.4 Mound springs flora and conservation significance relative to spring complex and spring group (continued)

Spring complex	Bare twigrush (A, L, B)	Spiny flat-sedge (U)	Bore-drain sedge (A)	Salt pipewort (A, L, T)	Common fringe-rush (A, L)	Cutting grass (A, L, B)	Sea rush (C, L, S)	Common reed (A)	Salt couch (A)	Cumbungi (C)
LAKE EYRE SUPERGROUP (continued)										
MOUNT DUTTON										
Allandale		X	X							X
Little Cadna-owie		X	X					X		X
Ockenden Proper		X	X							X
Wandillinna		X	X							X
LAKE CADIBARRAWIRRACANNA										
Cadi 1			X						X	
MOUNT MARGARET										
Tarlton		X	X							X
NEALES RIVER										
Big Perry		X	X					X		X
Brinkley		X								
Fanny		X	X				X			X
Hawker		X	X			X	X	X	X	X
Levi		X	X				X	X		
Milne		X	X							X
Outside		X	X					X	X	X
Primrose		X								X
The Fountain			X					X		
The Vaughan			X							
Twelve Mile		X						X		
PEAKE CREEK										
Birribiana		X	X							
Cardajalburrana		X	X					X		X
Cootabarcoolia		X	X							
Cootanoorina		X	X						X	X
Keckwick			X					X		X
Old Nilpinna		X								
Weedina		X	X						X	
Weedina North		X	X					X		
WANGIANNA										
Davenport			X							
Welcome		X	X							
BERESFORD HILL										
Beresford Hill			X					X		
LAKE FROME SUPERGROUP										
LAKE CALLABONNA										
Callabonna		X	X				X	X		X
MOUNT HOPELESS										
Petermorra (Chimney)			X	X						
Reedy		X	X							
Twelve			X	X	X			X		

Source: Fatchen and Fatchen (1993); D. Niejalke, WMC, pers. comm., October 1996.

A = Abundant. *S = Special significance.*
B = Biographically significant. *T = Threatened or endangered.*
C = Common. *U = Uncommon.*
L = Limited distribution. *X = Present.*

K2 VERTEBRATE FAUNA

This section discusses the vertebrate fauna associated with the mound springs.

K2.1 Mammals

As discussed in Kinhill (1995a), few mammal species are associated with mound springs in the region, and there are no species that rely on the mound springs as a habitat. Generally, the hard ground and lack of vegetation cover that surround the mound springs are unsuitable as habitat for burrowing animals, although the rocky areas bordering some mound springs (e.g. at Hermit Hill) may provide a suitable habitat for some of these species (e.g. dasyurids and rabbits). Table K.5 provides a list of mammal species that have been recorded in the mound springs region.

Two mammal species of threatened conservation significance have been recorded in the mound springs region—plains rat *(Pseudomys australis)* and Forrest's mouse *(Leggadina forresti)*. Both species are considered in more detail in Section 7.4.

Table K.5 List of mammal species recorded in the mound springs region and conservation status

Common name	Species name	Record	Australian status (Strahan 1995)	Australian status (ESP Act 1992)	SA status (SA NPW Act 1972)
NATIVE MAMMALS					
Stripe-faced dunnart	*Sminthopsis macroura*	O/SF	Common		
Fat-tailed dunnart	*S. crassicaudata*	O/SF	Common		
Kultarr	*Antechinomys laniger*	SF	Rare, scattered		Rare
Giles' planigale	*Planigale gilesi*	O/SF	Sparse		
Red kangaroo	*Macropus rufus*	O	Abundant		
Euro	*M. robustus*	O	Abundant		
White-striped freetail-bat	*Nyctinomus australis*	O/SF	Common to uncommon		
Long-haired rat	*Rattus villosissimus*	O/SF	Rare, occasionally in plagues		
Plains rat	*Pseudomys australis*	O/SF	Rare	Vulnerable	Rare
Forrest's mouse	*Leggadina forresti*	O/SF	Sparse		Rare
Bolam's mouse	*Pseudomys bolami*	O/SF	Uncommon		
Desert mouse	*Pseudomys desertor*	O	Secure and widespread		Rare
Mitchell's hopping-mouse	*Notomys mitchelli*	SF	Common		
Greater stick-nest rat	*Leporillus conditor*	SF	Rare, limited in range	Endangered	Endangered
INTRODUCED MAMMALS					
Dingo	*Canis lupus dingo*	O	Common to rare		Vermin south of the Dog Fence
European rabbit	*Oryctolagus cuniculus*	O	Abundant		
Cattle	*Bos taurus*	O	Common		
Horse	*Equus caballus*	O	Common		
House mouse	*Mus musculus*	EXP	Abundant		

O: Record by observation.
SF: Record from sub-fossil material.
EXP: Expected to be present.
ESP: Endangered species protection.
Sources: West 1985; D. Niejalke, WMC, pers. comm., November 1996.

Evidence of mammal species considered to be rare, endangered or presumed extinct in the region is present in sub-fossil material from near Yarra Wurta Spring, as indicated in Table K.6 (D. Niejalke, WMC, pers. comm., November 1996). These species are kultarr *(Antechinomys laniger)*, Gould's mouse *(Pseudomys gouldii)*, short-tailed hopping-mouse *(Notomys amplus)*, long-tailed hopping-mouse *(N. longicaudatus)*, greater stick-nest rat *(Leporillus conditor)*, lesser stick-nest rat *(L. apicalis)*, burrowing bettong *(Bettongia lesueur)*, western barred bandicoot *(Perameles bougainville)*, pig-footed bandicoot *(Chaeropus ecaudatus)* and golden bandicoot *(Isoodon auratus)*. It is probable that these animals, although present near Yarra Wurta Spring, were not directly associated with the spring but with the surrounding environment.

Table K.6 Extinct species recorded in sub-fossil material at Yarra Wurta Spring

Common name	Species name	Australian status (Strahan 1995)	Australian status (ESP Act 1992)	SA status (SA NPW Act 1972)
Gould's mouse	*Pseudomys gouldii*	Rare, probably extinct	Presumed extinct	Not listed
Short-tailed hopping-mouse	*Notomys amplus*	Extinct	Presumed extinct	Endangered, considered extinct
Long-tailed hopping-mouse	*N. longicaudatus*	Unknown, possibly extinct	Presumed extinct	Endangered, considered extinct
Lesser stick-nest rat	*Leporillus apicalis*	Rare, possibly extinct	Presumed extinct	Endangered, considered extinct
Burrowing bettong	*Bettongia lesueur*	Extinct[1]	Endangered	Endangered
Western barred bandicoot	*Perameles bougainville*	Extinct[1]	Endangered	Endangered
Pig-footed bandicoot	*Chaeropus ecaudatus*	Extinct	Presumed extinct	Endangered, considered extinct
Golden bandicoot	*Isoodon auratus*	Extinct[2]	Endangered	Endangered

ESP: Endangered species protection.
NPW: National Parks and Wildlife.
1 *Present on islands off the Western Australian coast; presumed extinct on the mainland.*
2 *Present on islands off the Western Australian coast and in Northern Territory; presumed extinct in Central Australia.*
Sources: West 1985; D. Niejalke, WMC, pers. comm., November 1996.

K2.2 Birds

Large numbers of birds (species and individuals) have been recorded only at springs with relatively large areas of open, shallow water (e.g. Emerald and The Bubbler springs). Most mound springs are used by relatively few bird species and low numbers of birds (Badman 1985). Resident breeding species have generally been recorded at mound springs that are well vegetated.

Badman (1985) recorded fifty-eight bird species in the vicinity of ten major spring groups. Of these fifty-eight species, nine were considered to be frequent visitors to the springs, nineteen were infrequent visitors, and thirty were occasional visitors (Table K.7). In addition, four of the species were recorded only at mound springs with extensive vegetation, and seven species were recorded only at The Bubbler spring or Emerald Spring. Many of these species are widespread in the arid zone and are not dependent on the mound springs for their survival (e.g. wedge-tailed eagle).

Table K.7 Bird species associated with mound springs

Common name	Species name	Frequency of visit	Australian status (ESP Act 1992)	SA status (SA NPW Act 1972)
Emu	*Dromaius novaehollandiae*	O		
Australian pelican	*Pelecanus conspicillatus*	O		
Little black cormorant	*Phalacrocorax sulcirostris*	O[1]		
White-faced heron	*Ardea novaehollandiae*	O[1]		
Glossy ibis	*Plegadis falcinellus*	O[1]		
Yellow-billed spoonbill	*Platalea flavipes*	O		
Australian shelduck	*Tadorna tafornoides*	O		
Pacific black duck	*Anas superciliosa*	I		
Grey teal	*A. gibberifrons*	F		
Maned duck	*Chenonetta jubata*	I		
Wedge-tailed eagle	*Aquila audax*	I		
Marsh harrier	*Circus approximans*	O		
Brown falcon	*Falco berigora*	I		
Australian kestrel	*F. cenchroides*	I		
Australian crake	*Porzana fluminea*	I1		
Black-tailed native-hen	*Gallinula ventralis*	I		
Purple swamphen	*Porphyrio porphyrio*	O[2]		
Brolga	*Grus rubicunda*	O		Vulnerable
Masked lapwing	*Vanellus miles*	I		
Banded lapwing	*V. tricolor*	O		
Red-kneed dotterel	*Erythrogonys cinctus*	O		
Red-capped plover	*Charadrius ruficapillus*	F		
Black-fronted plover	*C. melanops*	F		
Black-winged stilt	*Himantopus himantopus*	F		
Red-necked avocet	*Recurvirostra novaehollandiae*	O		
Wood sandpiper	*Tringa glareola*	O[1]	Protected	
Greenshank	*T. nebularia*	I[1]	Protected	
Sharp-tailed sandpiper	*Calidris acuminata*	F	Protected	
Australian pratincole	*Stiltia isabella*	I		
Silver gull	*Larus novaehollandiae*	O		
Whiskered tern	*Chlidonias hybridus*	O		
Crested pigeon	*Ocyphaps lophotes*	I		
Galah	*Cacatua roseicapilla*	F		Unprotected
Little corella	*C. sanguinea*	F		
White-backed swallow	*Cheramoeca leucosternus*	O		
Welcome swallow	*Hirundo neoxena*	O		
Tree martin	*H. nigricans*	O		
Richard's pipit	*Anthus novaeseelandiae*	I		
Crested bellbird	*Oreoica gutturalis*	O		
Willie wagtail	*Rhipidura leucophrys*	I		
Cinnamon quail-thrush	*Cinclosoma cinnamomeum*	O		
Clamorous reed-warbler	*Acrocephalus stentoreus*	O[2]		
Little grassbird	*Megalurus gramineus*	I[2]		

Table K.7 Bird species associated with mound springs (continued)

Common name	Species name	Frequency of visit	Australian status (ESP Act 1992)	SA status (SA NPW Act 1972)
Rufous songlark	*Cinclorhamphus mathewsi*	O		
Brown songlark	*C. cruralis*	O		
Variegated fairy-wren	*Malurus lamberti*	O		
White-winged fairy-wren	*M. leucopterus*	F		
Singing honeyeater	*Lichenostomus virescens*	I		
White-plumed honeyeater	*L. penicillatus*	O		
Crimson chat	*Ephthianura tricolor*	O		
Orange chat	*E. aurifrons*	I		
White-fronted chat	*E. albifrons*	O[2]		
Zebra finch	*Taenioplygia guttata*	I		Unprotected
Australian magpie-lark	*Grallina cyanoleuca*	O		
Black-faced woodswallow	*Artamus cinereus*	I		
Australian magpie	*Gymnorhina tibicen*	O		
Australian raven	*Corvus coronoides*	I		Unprotected
Little crow	*C. bennetti*	F		Unprotected

1 Species sighted only at mound springs with extensive vegetation.

2 Species sighted only at The Bubbler or Emerald Spring.

Frequency: F: Frequent (species was sighted at more than 60% of visits).

I: Infrequent (species was sighted at between 20–60% of visits).

O: Occasional (species was sighted at between 1–20% of visits).

Source: Adapted from Badman 1985.

In comparison with the mound springs, wetlands associated with bore drains provide suitable habitat for a larger number of bird species and greater population densities. Prior to the drilling of bores, the mound springs and their vegetated wetlands would have been crucial for the survival of many bird species in the arid zone. In addition, the mound springs would have acted as refuges for many bird species in times of drought, and as roosting and resting points for migratory bird species. The bore drains now provide these necessary habitats (Badman 1985).

Some bird species of conservation significance have been recorded in the vicinity of the mound springs—brolga *(Grus rubicunda)*, wood sandpiper *(Tringa glareola)*, greenshank *(T. nebularia)* and sharp-tailed sandpiper *(Calidris acuminata)*. In addition, significant species, such as the grass owl *(Tyto capensis)* may begin to use mound spring habitats following the eradication of cattle and European rabbit.

The brolga is listed as a vulnerable species under the *South Australian National Parks and Wildlife Act 1972*. Pairs of brolgas have been recorded at several spring groups, including those of the Hermit Hill spring complex, and in the vicinity of springs and bores on Callana (G. Morphett, Callana Station, pers. comm., November 1994) and Muloorina stations (Kinhill 1995a). Birds such as brolgas visiting mound springs may act as important dispersal agents for mound springs flora and fauna (Read and Niejalke 1996).

Wood sandpiper, greenshank and sharp-tailed sandpiper are listed as protected migratory birds under the Commonwealth *National Parks and Wildlife Conservation Act 1975*, and are listed under both JAMBA and CAMBA migratory bird agreements. These birds are commonly found on shallow waters across most of Australia from August–September to April–May each year. At the end of the southern summer these birds return to their breeding grounds in the northern hemisphere.

K2.3 Reptiles and amphibians

Seventeen reptile species were reported in the vicinity of mound springs by Thompson (1985). A list of these species is provided in Table K.8. These reptiles do not appear to be specifically associated with the mound springs but are associated with the habitats in the vicinity of springs.

Owing to the salinity of the mound spring water, these areas do not generally provide habitats for any frog species (Thompson 1985). An exception to this is the introduced population of *Limnodynastes tasmaniensis* at Dalhousie Springs.

Table K.8 Reptile species recorded in the vicinity of mound springs

Common name	Species name	Habitat
Gidgee skink	*Egernia stokesi*	Spring
Skink	*Menetia greyii*	Spring/extinct spring
Skink	*Morethia adelaidensis*	Spring
Skink	*Ctenotus brooksi*	Spring
Skink	*Ctenotus* sp.	Extinct spring
Shingle-back	*Trachydosaurus rugosus*	Extinct spring
Skink	*Lerista muelleri*	Extinct spring
Skink	*Crytoblepharus plagiocephalus*	Extinct spring
Tree dtella	*Gehyra variegata*	Spring/extinct spring
Legless lizard	*Delma australis*	Spring
Bynoe's gecko	*Heteronotia binoei*	Spring/extinct spring
Thick-tailed gecko	*Underwoodisaurus millii*	Extinct spring
Earless dragon	*Tympanocryptis intima*	Spring/extinct spring
Painted dragon	*Ctenophorus pictus*	Spring
Bearded dragon	*Amphibolurus vitticeps*	Spring/extinct spring
Sand goanna	*Varanus gouldii*	Spring
Western brown snake	*Pseudonaja nuchalis*	Extinct spring

K2.4 Invertebrate fauna

This section provides information about invertebrate fauna associated with mound springs and includes:

- Table K.9, spiders associated with mound springs wetland habitats
- Table K.10, endemic invertebrates recorded according to spring groups and complexes.

Table K9 Spiders associated with mound springs wetland habitats assessed by WMC

Family	Species name
Desidae	sp.
	Phryganoporus sp.
Zoridae	*Thasyrea* sp.
Miturgidae	*Miturga* sp.
Pisauridae	*Dolomedes* sp.
Hahniidae	*Alistra* sp.
Oxyopidae	*Oxyopes dingo*
Heteropodidae	*Isopedella inola*
Clubionidae	*Clubiona* sp.
	?Corinomma sp.
Gnaphosidae	spp. (x4)
Salticidae	sp.
	Bianor sp.
	Jotus sp.
	Lycidae sp.
	Maratus sp.
	?Prostheclina sp.
Zodariidae	*Habronestes* sp.
Lycosidae	*Lycosa* spp. (x2)
	Lycosa arenaris
	L. arenaris group
	Trochosa cf. *oraria*
	Trochosa spp. (x3)
Tetragnathidae	*Tetragnatha* sp.
Araneidae	*Araneus* spp. (x3)
	Argiope sp.
	A. ?protensa
	A. ?trifasciata
	Eriophora sp.
	Nephila edulis
Linyphiidae	*?Dunedinia* sp.
	Eriogone prominens
	?Laetesia sp.

Sources: Darren Niejalke, WMC, pers. comm., December 1996;
David Hirst, SA Museum, pers. comm., December 1996.

Table K.10 Spring groups and complexes in which endemic invertebrates have been recorded

Spring complex	Spring group	Amphipods	Isopods	Ostracods	*Fonscochlea*	*Trochidrobia*
LAKE EYRE SUPERGROUP						
Beresford Hill	Beresford Hill	1,4	1,4	1,4	1,2,4	1,2,4
	Warburton	1	1	1	1,2	1,2
Billa Kalina	Billa Kalina	1,4	1,4	1,4	1,2,4	1,2,4
Coward	Blanche Cup	1	1,4	1	1,2,4	1,2
	Buttercup				4	
	Coward	1	1	1	1,2	1,2
	Coward Springs Railway Bore				1	1,2
	Elizabeth	1,4	1,4	1,4	1,2,4	1,2,4
	Horse	1,4	1,4	1,4	1,2,4	1,2,4
	Jersey	1,4	1,4	1,4	1,2,4	1,2,4
	Julie	1	1	1	1,2	1,2
	Kewson Hill	1,4	1,4	1	1,2,4	1,2,4
	Little Bubbler	1,5	1,5	1,5	1,2,5	1,2,5
	The Bubbler	1	1	1	1,2	1,2
	Mount Hamilton Ruins			1	1,2,4	1,2
	Strangways	1,4	1,4	1,4	1,2,4	1,2,4
Francis Swamp	Bishop	1	1		1 (H)	1 (H)
	Emily			4	4	4
	Francis Swamp	1,4	1,4	1,4	1,4	1,4
	Lloyd Bore	1	1	1	1	1
	Margaret			1 (S)	1,2 (S)	1,2 (S)
	William		4	4		
Hermit Hill	Beatrice			1		
	Bopeechee	1,4,5	1,4,5	1,4,5	1,2,4,5	1,2,4,5
	Dead Boy	1,4,5	1,4,5	1,4,5	1,2,4,5	1,2,4,5
	Hermit Springs	1,4,5	1,4,5	1,4,5	1,2,4,5	1,2,4,5
	Old Finniss	1,5	1,5	1,5	1,2,5	1,2
	Old Woman	1,5	1,5	1,5	1,2,4,5	1,2,5
	Northwest	1	1	1		
	Sulphuric	1,4,5	1,4,5	1,4,5	1,2,4,5	1,2,4,5
	West Finniss	1,4,5	1,4,5	1,4,5	1,2,4,5	1,2,4,5
	Venable		1	1	1,2 (S)	1,2 (S)
Lake Cadibarrawirracanna	Cadi 1			4		
Lake Eyre	Centre Island			1	1,2 (S)	2 (S)
	Emerald	1	1,4	1,4	1,2	
	Fred East			1,4		
	Gosse			1		
	McLachlan (northern)			1		
	Priscilla			1 (S)	1,2 (S)	1,2 (S)
	Smith*			1		
Mount Denison	Garnet (north of Freeling)		4	4		
	Sandy Creek			4		

Table K.10 Spring groups and complexes in which endemic invertebrates have been recorded (continued)

Spring complex	Spring group	Amphipods	Isopods	Ostracods	*Fonscochlea*	*Trochidrobia*
LAKE EYRE SUPERGROUP (continued)						
Mount Dutton	Allandale			4		
	Big Cadna-owie			1,4	1,2,4	
	Little Cadna-owie			1,4		
Neales River (including Mount Margaret)	Big Perry	1	1,4	1	1,2,3	1,2
	Brinkley	4	1,4	1	1,2,4	1,2,4
	Edith			1		
	Fanny		4	4	4	4
	Hawker	1,4	1,4	1,4	1,2,4	1,2,4
	Levi			1,4	4	
	Melon			1		
	Milne		4	1,4		
	Outside	1,4	1,4	1,4	1,2,4	1,2,4
	Primrose			4		
	Spring Hill			1	1,2 (S)	
	Tarlton			1	4	
	The Fountain	1,4	1,4	1	1,2,4	1,2
	The Vaughan	1	1	1	1 (H)	1 (H)
	Twelve Mile	1	1,4	1,4	1,2,4	1,2
Oolgelima				4		
Peake Creek	Birribiana			4		
	Cardajalburrana			4		
	Freeling	1	1		1,2	1,2
	Freeling (bore)	1	1	1	1 (H)	1 (H)
	Keckwick			4		
	Nilpinna			4		
	Oortookoolana			4		
	Weedina			4		
	Unnamed (Peake Creek)	1	1	1	1 (H)	1 (H)
Wangianna	Davenport	1,4,5	1,4,5	1,4,5	1,2,4,5	1,2,4,5
	Wangianna			3		
	Welcome	1,3	1,3,4	1,3,4	1,2,3,4	1,2,3
LAKE FROME SUPERGROUP						
Mount Hopeless	Reedy			4*		
Lake Callabonna	Callabonna				4*	

1 *Recorded in Kinhill Stearns 1984.*
2 *Recorded in Ponder et al. 1989.*
3 *Recorded in Kinhill 1995b.*
4 *Recorded by D. Niejalke, WMC, 1995–96.*
5 Recorded in *Kinhill 1997.*
(H) = no differentiation recorded between Fonscochlea *and* Trochidrobia.
(S) = no live specimens collected, shells only.
* *Unlikely to be an endemic species.*

K2.5 Description of hydrobiids recorded in the Lake Eyre supergroup

The distribution of hydrobiids in the Lake Eyre supergroup is provided in Table K.11.

Fonscochlea zeidleri

Fonscochlea zeidleri is a large amphibious species with a very wide distribution in mound springs of the Lake Eyre supergroup. The shell of this species is very similar to *F. accepta* and *F. aquatica* in size and shape; however, differences are present in shell thickness and whorl morphology (Ponder et al. 1989). There are two distinct groups within this species, one of which is located in the northern springs and the other in the north-western springs of the Lake Eyre supergroup.

Fonscochlea accepta

Fonscochlea accepta is a large aquatic species recorded in mound springs located in the southern section of the Lake Eyre supergroup (Ponder et al. 1989, 1995). Studies by Ponder et al. (1989) recorded that this species is generally abundant in the mound springs vent pool and in the vent outflow. However, it has been recorded clustering at the side of the vent outflow, but retains a thin film of water if emergent.

Fonscochlea aquatica

Fonscochlea aquatica is a large amphibious species with a wide distribution in the mound springs of the Lake Eyre supergroup but notably absent from the mound springs of the Hermit Hill spring complex. The shell of this species is larger than *F. accepta*. Studies by Ponder et al. (1995) recorded two distinct groups within this species, although the presence of overall morphological similarity does not warrant taxonomic differentiation. One group includes the populations from Blanche Cup north-west to Beresford Springs, and the second group includes the populations from Strangways Springs north to Freeling Springs.

Fonscochlea billakalina

Fonscochlea billakalina is a small aquatic species restricted to the Billa Kalina, Strangways and Francis Swamp spring complexes of the Lake Eyre supergroup. The shell morphology of this species is virtually identical to that of one of the groups of *F. variabilis* (Ponder et al. 1989). However, results of genetic studies by Ponder et al. (1995) indicate that this species is very distinct from the other small aquatic hydrobiid taxa.

Fonscochlea variabilis

Fonscochlea variabilis is a small aquatic species with a wide distribution in the mound springs of the Lake Eyre supergroup. The species name reflects the variability in the shell morphology of this hydrobiid. Studies by Ponder et al. (1989) recorded that this species prefers to inhabit the upper vent and outflow of mound springs and attaches itself to the underside of hard objects in the water (e.g. stones, wood, bones). There are two distinct groups within this species that are both genetically different and occur in different geographical locations (Ponder et al. 1995).

Fonscochlea expandolabra

Fonscochlea expandolabra is a small aquatic species recorded in only two northern spring complexes (Neales River and Peake Creek). This species was formerly described in Ponder et al. (1989) as forms B and C of *F. variabilis*. Recent studies by Ponder et al. (1995) have differentiated *F. expandolabra* from *F. variabilis* using shell and operculum measurements, and genetic analysis.

Table K.11 Distribution of hydrobiids in springs and spring groups in the Lake Eyre supergroup

Spring complex	*Fonscochlea zeidleri*	*Fonscochlea aquatica*	*Fonscochlea accepta*	*Fonscochlea variabilis*
BERESFORD HILL				
Beresford group	X	X		X
Warburton group	X	X		X
BILLA KALINA				
Billa Kalina	X	X		
Fenced spring	X	X		X
Welcome Bore spring	(S)			
COWARD				
Blanche Cup group	X	X		X
Coward Springs group	X	X		X
Coward Springs railway bore	X			X
Elizabeth group	X	X		X
Horse group(s)	X	X		X
Jersey group	X	X		X
Julie group	X	X		X
Kewson Hill group	X	X		X
Little Bubbler spring	X	X		X
Mount Hamilton spring	X	X		X
Strangways spring	X	X		X
The Bubbler spring	X	X		X
FRANCIS SWAMP				
Francis Swamp group	X	X		
Lloyd Bore spring	X	X		
Margaret spring	(S)	(S)		
HERMIT HILL				
Bopeechee spring	X		X	X
Dead Boy spring			X	
Hermit Spring group	X		X	
Old Finniss group	X		X	
Old Woman group	X		X	X
Sulphuric group			X	
Venable spring	(S)		(S)	(S)
West Finniss group	X		X	(S)
LAKE EYRE				
Centre Island spring	(S)			
Emerald spring			X	
Priscilla spring	(S)		(S)	(S)
MOUNT DUTTON				
Big Cadna-owie	X			
NEALES RIVER (including Mount Margaret)				
Big Perry spring	X	X		
Brinkley spring	X	X		
Hawker group	X	X		
Outside group	X	X		
Spring Hill group	(S)			
The Fountain group	X	X		
Twelve Mile group	X	X		
PEAKE CREEK				
Freeling group	X	X		
North of Freeling group				
STRANGWAYS				
Strangways group	X	X		
WANGIANNA				
Davenport group	X		X	X
Welcome group	X		X	X

Source: Ponder et al. 1989; 1995. X = live animal present. S= shell only.

	Fonscochlea billakalina	*Fonscochlea expandolabra*	*Trochidrobia punicea*	*Trochidrobia smithi*	*Trochidrobia minuta*	*Trochidrobia inflata*
				X		
				X		
	X			X		
				X		
	(S)					
			X			
			X			
			X			
			X			
			X			
			X			
			X			
			X			
			X			
			X			
			X			
	X			X		
	X			X		
	(S)			(S)		
			X			
			X			
			X			
			X			
			X			
			X			
			(S)			
			X			
			(S)			
		X		X	X	
				X		
		X		X		
		X		X	X	
		X		X	X	
		X		X	X	
		X			X	X
					X	
	X			X		
			X			
			X			

Trochidrobia punicea

Trochidrobia punicea is a small aquatic species with a relatively wide distribution in mound springs of the Lake Eyre supergroup. The shell of this species is almost identical to that of *T. smithi* (Ponder et al. 1989). The species is abundant is most springs in which it has been recorded. Its microhabitat is non-specific, and records have shown the species to be particularly abundant in shallow spring outflows with a firm substrate (Ponder et al. 1989).

Trochidrobia smithi

Trochidrobia smithi, like *T. punicea,* is a small aquatic species and has a relatively wide distribution in mound springs of the Lake Eyre supergroup. In addition, the ecology of this species is considered to be very similar to that of *T. punicea* (Ponder et al. 1989).

Trochidrobia minuta

Trochidrobia minuta is a very small aquatic species, as is reflected in its name. The shell is pale in comparison with *T. punicea* and *T. smithi.* Distribution is limited to the northern spring complexes (Neales River and Peake Creek) of the Lake Eyre supergroup. Studies by Ponder et al. (1989) record the species as mostly present in the upper and middle parts of spring outflows.

Trochidrobia inflata

Trochidrobia inflata is a small aquatic species that is limited in distribution to the Freeling spring complex of the Lake Eyre supergroup. The relatively high spire of this species distinguishes it from others in the genus. The greatest population abundance of this species has been recorded in the lower parts of the spring outflows (Ponder et al. 1989).

K3 MOUND SPRINGS MONITORING

WMC monitors the following aspects of the mound springs:

- vegetation
- invertebrate fauna
- water flow rate and quality.

A description of each of these monitoring programmes is provided in the following text.

K3.1 Vegetation

The mound spring vegetation monitoring programme used by WMC and its consultants has been derived from the findings of the 1983 baseline survey and from a resurvey of the same springs during 1986. The annual monitoring programme currently used commenced in 1987 for all spring complexes except Marree. Full details of this monitoring programme are in WMC—Olympic Dam Corporation (1996), and survey methodology is detailed in Fatchen and Fatchen (1993).

There are two components to the vegetation monitoring programme: a rapid survey of many springs, and a more intensive transect survey of a limited number of springs.

The major component of the vegetation monitoring programme is repeated rapid survey of spring groups within the Hermit Hill, Lake Eyre, Coward, Marree (from 1995) and Wangianna spring complexes. Species presence, estimates of relative species abundance, and condition are recorded annually from each of over 350 mound springs and their wetlands.

Rapid survey is supplemented by intensive sampling of a smaller number of springs in order to assess species of particular conservation significance. Permanent belt transects at springs within the Hermit Hill spring complex provide detailed information of total plant cover and year-to-year changes in the distribution of species. Belt transects comprise a series of 1 m^2 quadrats across each spring. Monitoring is supported by photographs from permanent photopoints at each of the intensively monitored springs.

K3.2 Invertebrate fauna

Ongoing mound springs endemic and aquatic macroinvertebrates (amphipods, isopods, ostracods and hydrobiids) and other non-endemic invertebrates are monitored as part of the ongoing Mound Springs Invertebrate Fauna Monitoring Programme (MSFMP).

The MSFMP was implemented in August 1986 as a means of assessing the impact on the aquatic spring fauna of aquifer drawdown associated with the operation of Borefield A. The programme monitors a representative sample of springs from four spring complexes within 60 km of the borefield (Table K.12).

The presence and abundance of isopods, amphipods, hydrobiids and ostracods and the general species richness of aquatic invertebrates were sampled at each spring until the October 1995 survey, when ostracods were removed from the programme for reasons outlined in Kinhill (1996). In addition, water quality data, such as pH, conductivity and temperature, are recorded at each spring.

Survey methods do not include the establishment of permanent sample points, as random changes to spring morphology, particularly the orientation and distribution of the spring tail, are common.

Table K.12 Mound springs of the Lake Eyre supergroup monitored over the term of the Mound Springs Invertebrate Fauna Monitoring Programme

Spring complex	Spring group	Spring identifier code
Coward	Blanche Cup	CBS002
Hermit	Bopeechee	HBO004
	Dead Boy	HDB005
	Hermit Springs	HHS028, HHS035, HHS101, HHS125, HHS137
	Old Finniss	HOF004, HOF033, HOF092
	Old Woman	HOW009, HOW015
	Sulphuric	HSS000, HSS012
	Venable	HVS001
	West Finniss	HWF026, HWF029
Lake Eyre	Gosse	LGS004
	Priscilla	LPS001
Wangianna	Davenport	WDS001

Monitoring programme pre-1995

Sampling methods prior to October 1995 included taking three randomly placed samples from each spring for quantitative population analyses, and one additional qualitative sample from all microhabitats for the analysis of species diversity. In addition, each monitored spring and numerous other springs from the same group were assessed for spring 'health' using a spring classification system. This system is outlined in Table K.13. Fixed photopoint photographs were also taken of each spring.

Table K.13 Spring 'health' classification

Spring class	Description	Aquatic habitat
1	Extinct spring	None
2	Seep with no surface water and vegetation	None
3	Spring with very thin surface film and little flow or vegetation	Poor
4	Spring with open water vent but no tail and low flow and vegetation	Marginal
5	Spring with well-developed tail with flowing water and vegetation	Good

Spring samples were preserved in the field and samples returned to the laboratory. In the laboratory the quantitative samples were sieved and sorted, and numbers of each of the endemic invertebrate taxa were recorded. Information on the population density of these taxa was extrapolated from these data. The qualitative sample was also sieved and sorted, and all taxa in the sample identified. This sample provided species richness data. Endemic invertebrate taxa were sorted and recorded to genus level, whereas other aquatic fauna were sorted and generally recorded to family level only.

A detailed description of the sampling and sorting procedures is provided in Kinhill (1995b).

Monitoring programme during and post-1995

Prior to the 1995 survey, WMC and its consultants recognised the need to update and revise the current MSFMP. Subsequently, new sampling procedures have been established that enable:

- a greater number of samples to be taken from each spring;
- identification of most endemic mound springs taxa to a higher taxonomic level where possible; for example, species rather than genus.

The new procedures involve taking six quantitative samples along four transects at each spring (twenty-four samples per spring). The transects are placed at equal distances along the length of the spring tail, starting at the beginning of the spring tail. The first and last quadrats of each transect are placed on saturated mud within 10 cm of the flowing water perimeter and the remaining four at equal distances along the transect.

Spring samples are preserved in the field and returned to the laboratory, where they are sieved and sorted to extract all of the taxa present. The numbers of each endemic invertebrate taxon are recorded and the other aquatic taxa removed to be identified for species richness analysis.

Information on the population density of the endemic taxa is extrapolated from the counts and species richness data obtained from the remaining taxa. Endemic invertebrate taxa are sorted and recorded generally to species level, whereas the other aquatic fauna are generally sorted and recorded to family level.

Spring classifications and photopoint photography are no longer undertaken as part of the MSFMP to avoid duplication with the mound springs vegetation programme. A detailed description of the procedures undertaken in this programme is provided in the mound springs monitoring report (Kinhill 1996). Results of the MSFMP are provided by WMC in the WMC Environmental Management and Monitoring Programme annual reports.

K3.3 Water flow rate and quality

Water flow rate is monitored monthly by WMC (WMC—Olympic Dam Corporation 1996) and its consultants biannually (Land Use Consultants 1996). Spring flow measurements are taken from forty-one springs. Since 1984 the measurement of spring flow has been carried out either by dye or weir gauging.

Basic water chemistry is assessed by WMC quarterly. In addition, WMC assesses full water chemistry annually. Water for these analyses is collected as near as possible to each spring vent.

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APPENDIX L

AIR QUALITY

HOLMES AIR SCIENCES

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APPENDIX L

AIR QUALITY

CONTENTS

FIGURE

TABLES

L1 INTRODUCTION

This report has been prepared by Holmes Air Sciences on behalf of Kinhill Engineers Pty Ltd who are preparing an environmental impact statement for WMC (Olympic Dam Corporation) Pty Ltd's expansion of the Olympic Dam Copper Uranium Division plant at Olympic Dam.

The purpose of the report is to assess the air quality impacts due to emissions of sulphur oxides, nitrogen oxides, carbon monoxide, hydrogen fluoride and particulate matter from the existing and expanded plants. The impact of emissions of radionuclides (gases and particles) is dealt with in a separate assessment.

The Olympic Dam operation comprises an underground mine and underground and surface ore processing facilities. The surface facilities are of most significance for this assessment. A brief overview of these is provided in Section L2. The surface components of the mining operation will result in the generation of fugitive dust from vehicle movements, ore handling, wind erosion, etc. However, as will be seen from the review of existing monitoring data the effects of fugitive dust are localised and do not affect residential areas or nearby vegetation.

Relatively simple control technologies (water sprays, etc.) are available to manage fugitive dust impacts should this prove necessary from time to time. Further, fugitive dust emissions are not expected to change significantly as a result of the expansion. For this reason no attempts to model the dispersion of fugitive dust emissions are made in this assessment. Rather, attention has been focused on assessing the impacts of SO_2 and other emissions from the surface ore processing facilities. These will change significantly as a result of the expansion.

The locations of the mine, the plant, the tailings retention system and monitoring sites are shown in Chapter 9, Figure 9.1. These sites will be referred to later in the report.

L2 OUTLINE OF EXISTING OPERATIONS AND THE PROPOSAL FROM AN AIR QUALITY PERSPECTIVE

The description provided below is brief and is provided for the reader to gain an overview of the existing operation and planned expansion, with an emphasis on air quality aspects. A more complete description is provided in Chapter 3 of the EIS.

L2.1 Process overview

The planned operation would use the same mining and ore processing technology and, to a large extent, the same plant. The new smelters and acid plants use similar processing technology but would be significantly different in environmental performance. In particular, peak sulphur dioxide emissions for the new smelter would be significantly lower than for the existing smelter.

The existing facility produces ore containing copper, gold, silver and uranium from an underground mine. Ore and mullock are crushed underground to a nominal 200 mm size by a 550 t/h jaw crusher and brought to the surface by conveyor. Ore is then loaded by tripper conveyor to a 35,000 t stockpile (live capacity 12,000 t), approximately 60 m long and 30 m wide. The remaining material in the stockpile is accessed by bulldozer.

Mullock is loaded to a separate stockpile where it is recovered by front-end loader, crushed and returned to the mine as backfill. A separate quarry is also operated to produce additional material required as backfill for the mine.

Ore is recovered from the live stockpile by a gravity-fed underground reclaim system, which supplies ore to an autogenous mill, ball mill and pebble crushing circuit (ABC circuit).

A flotation section is used to separate sulphur-containing ore. Both the tailings and concentrate are leached to recover uranium and the leached concentrate is further processed in flotation cells to produce a sulphur-containing copper concentrate which is filtered, dried and fed to a flash furnace. Preliminary refining of the copper is undertaken in anode furnaces, and copper anodes are cast on a casting wheel. The copper anodes are then electrolytically refined to produce high purity copper cathodes.

Fine materials recovered from the electrolytic refining tanks, referred to as slimes, are treated to produce silver and gold. Residual copper and uranium are removed from the tailings leach liquor by solvent extraction. The residual extracted copper is sent to the refinery for recovery by electrowinning, and uranium is precipitated, calcined and packaged in drums.

Tailings are separated into a coarse (sand) and fine fraction (slime). The coarse fraction is used as backfill and the slimes are stored in tailings dams.

L2.2 Principal emission sources

The most significant sources of non-radionuclide air pollutants are the copper smelter furnaces and the acid plant.

Concentrate is dried to a fluid powder and transported to one of two 1,000 t storage bins. A pneumatic conveying system transfers the dried concentrate powder to a 75 t day bin. This material is transferred with flux (mainly silicon dioxide) and dust to the flash furnace where oil burners heat the mixture and initiate the combustion of copper sulphide to form copper oxide and sulphur dioxide. Air enriched with oxygen (85 to 90%) is injected to facilitate the combustion. Blister copper from the flash furnace is ducted to the anode furnace.

The off-gas from the flash furnace is rich in sulphur dioxide and is ducted to the gas cooling and cleaning systems and then to the acid plant, for conversion to sulphuric acid, which is utilised in the hydrometallurgical plant.

Slag from the flash furnace is periodically tapped and passed by launders to an electric furnace for further recovery of copper. Slag from the electric furnace is tapped into pots where it is slowly cooled, crushed and returned to the autogenous mill. Blister copper from the electric furnace is tapped to 3 t pots and cooled after which it is charged to the anode furnace, in which preliminary refining is undertaken in a cyclical process repeated every eight hours.

In the anode furnace, oxygen is initially injected into the molten copper, and dissolved sulphur is oxidised. Slag is skimmed from the surface of the furnace. When the sulphur level is lowered to 0.005% the process is stopped and dissolved oxygen is removed by injecting the copper with LPG, which provides reducing conditions. When the dissolved oxygen is below 0.15% the copper is cast into anodes. The highest sulphur dioxide emissions occur in the smelter during the oxidising phase of the anode furnace operation.

The principal improvement in sulphur dioxide emission control for the new smelters will be the ducting of sulphur dioxide rich off-gases from the anode furnaces to the new acid plants. This will significantly reduce the short-term elevated sulphur dioxide emissions that occur from the operation of the existing anode furnaces during the oxidising phase.

L3 AIR QUALITY GOALS

Air quality is generally managed by specifying both concentration limits of emissions within the stack and ambient air quality goals. Concentration limits within the stack are determined primarily by what is technologically achievable. These limits are used by regulatory agencies to ensure that appropriate technology is being used both in processing plant and in the pollution control equipment.

Pollutant concentrations in the stack emissions and the volume of processed gases determine the mass emission rate of pollution from a particular operation. In turn the mass emission rates will determine the resulting ambient air quality. The connection between the mass emission and ambient air quality is indirect and depends on the height of the stack through which the waste gases are discharged, the temperature of the gases, and the prevailing meteorological conditions.

In summary stack emission limits and the ambient air quality goals are connected, but both serve slightly different purposes. The stack emission limits are determined primarily by technological factors. Ambient air quality goals are determined primarily by environmental factors and are designed to ensure that the environment is protected regardless of the cost or inconvenience that this may impose on the process technology.

L3.1 Ambient air quality goals

The South Australian Office of the Environment Protection Authority (SA EPA) nominates ambient air quality goals for nitrogen dioxide (NO_2), carbon monoxide (CO), total suspended particulate matter (TSP), lead and sulphur dioxide (SO_2). These goals are set out in Table L.1. In addition to the SA EPA goals, WMC has made reference to other air quality goals that are relevant to the project. These are PM_{10} (particulate matter with an aerodynamic diameter of less than 10 µm) and $PM_{2.5}$ (particulate matter with an aerodynamic diameter of less than 2.5 µm) and fluoride (expressed as HF). These goals are also listed in Table L.1 along with the body that has determined them.

The project design criteria are also included in Table L.1. These design criteria apply to individual expansion stages. They are lower than the SA EPA goals to make allowance for cumulative effects that will occur due to future expansion. The SA EPA criteria are required to be met for the overall plant.

Table L.1 Relevant ambient air quality criteria, µg/m³

Pollutant	SA EPA criteria	Possible future SA EPA criteria	Project design criteria[1]	Sources/notes
NO_2	320 (1-hour)		210 (1-hour)	NHMRC;1 exceedance/month
CO	40,000 (1-hour) 10,000 (8-hour)		23,000 (1-hour) 6,000 (8-hour)	NHMRC
Total suspended particulates	75 (annual)[2] 260 (24-hour)		50 (annual) 175 (24-hour)	US EPA[3]
PM_{10} particulates		50 (annual) 150 (24-hour)	33 (annual) 100 (24-hour)	US EPA 1 exceedance/year; under review
$PM_{2.5}$ particulates		30 (annual) 85 (24-hour)	20 (annual) 55 (24-hour)	US EPA review proposals: 15–30 (annual mean), 25–85(24-hour)
Lead	1.5 (3-month)	1.0 (3-month)	0.65 (3-month)	NHMRC ; under review
SO_2[4]	60 (annual) 570 (1-hour)[5] 700 (10-minute)[5]		40 (annual) 350 (1-hour) 460 (10-minute)	NHMRC
Fluoride (as HF)		3.7 (12-hour) 2.9 (1-day) 1.7 (7-day) 0.84 (30-day) 0.5 (90-day)	2.7 (12-hour) 1.9 (1-day) 1.1 (7-day) 0.55 (30-day) 0.33 (90-day)	ANZECC

1 *Applies individually to each project expansion stage. Overall levels must meet SA EPA requirements.*
2 *Geometric mean. NHMRC goal is 90 µg/m³, annual mean.*
3 *Replaced by PM_{10} standards in the USA.*
4 *SO_2 is at STP, others at 20°C.*
5 *Recently lowered from 700 µg/m³ (1-hour) and 1,400 µg/m³ (10-minute).*
Notes: NHMRC = National Health and Medical Research Council; USEPA = United States Environment Protection Authority; ANZECC = Australian and New Zealand Environment and Conservation Council.

L3.2 Stack emission limits

The SA Environment Protection Act 1993 Air Quality Policy specifies stack emission limits. National emission guidelines for new stationary sources are also issued by the Australian Environment Council and the National Health and Medical Research Council (NHMRC) (Australian Environment Council and National Health and Medical Research Council 1986). Table L.2 lists the emission limits and guidelines that are relevant for the existing plant and the expansion. WMC has also determined project design limits which are set out in Table L.2. In most cases the project design limit is less than the SA EPA limit.

Table L.2 Relevant SA EPA emission limits and national guidelines (mg/Nm^3, dry)

Pollutant	SA EPA limit	National guidelines	Project design limit	Notes
Antimony	10	–	5	
Arsenic	10	–	5	
Cadmium	3	3	2	
Lead	10	–	5	
Mercury	3	3	2	
Vanadium	–	–	2[1]	
Selenium	–	–	2[1]	
Tellurium	–	–	2[1]	
Cobalt	–	–	2[1]	
Manganese	–	–	2[1]	
Nickel	–	20	2	National standard may be reduced in future
Total metals	10[2]	10[3]	7.5[4]	
Particulates	250	250	100	General processes (referenced to 12% CO_2 for boilers and incinerators)
Particulates	100	100	75	Heating or processing ores and metals
Acid gases	3,000	–	2,500	Acid plants as SO_3 equivalent (total of H_2SO_4, SO_3, SO_2)
Sulphur dioxide	–	2.0	2.0	Units are kg/t of 100% acid
(H_2SO_4 plants)	–	–	99.8%	Acid plants—removal efficiency
Sulphur dioxide	–	–	1,200[5]	Other than acid plants
Sulphuric acid/	100	–	75	Acid plants as SO_3 equivalent
sulphur trioxide	–	0.075	0.075	Units are kg/t of 100% acid or equivalent
Oxides of nitrogen	350	350	300	Gaseous fuels—possible future limit
	500	500	450	Liquid fuels (>150,000 MJ/h, limit referenced to 7% O_2)
	500	500	450	Solid fuels (>150,000 MJ/h, limit referenced to 7% O_2)
	–	–	400[6]	Non-combustion and non-acid plant sources
Hydrogen sulphide	5	5	3	
Fluorine and compounds	50	50	20[7]	As HF equivalent
Chlorine and compounds	200	200	150	As Cl_2 equivalent
Carbon monoxide	1,000	1,000	750	

1 *Could be included in future metals standards.*

2 *Total of antimony, arsenic, cadmium, lead and mercury and their respective compounds.*

3 *Total of antimony, arsenic, cadmium, lead, mercury and vanadium and their respective compounds.*

4 *Total of antimony, arsenic, cadmium, lead, mercury, vanadium, selenium, tellurium, cobalt, manganese, nickel and their respective compounds.*

5 *Future possible limit is 1,400 mg/m^3.*

6 *Future possible limit is 500 mg/m^3.*

7 *Future possible limit is 20 mg/m^3.*

L4 EXISTING ENVIRONMENT

This section provides a brief description of meteorological and air quality monitoring programmes undertaken by WMC to determine meteorological factors which are significant for the management of air emissions from the existing plant, and which are required for assessing the impact of emissions from the expansion.

Air quality monitoring programmes are conducted to test for compliance with air quality guidelines, to quantify the impact of the plant on the environment and to provide a database for diagnostic analysis should unforeseen environmental effects be identified in flora and fauna monitoring programmes.

L4.1 Meteorological monitoring programmes

The Olympic Dam project has maintained meteorological monitoring stations in the vicinity of the plant since the first environmental studies commenced in the early 1980s. The existing operation commenced in 1988.

Three meteorological monitoring stations were in operation in 1988 at the time of commencement of operations. These are referred to as Sandhill, ODV and NTS. The locations of these meteorological stations are shown in Figure 9.1. Each of these monitoring stations was equipped to monitor and log half hour averages of wind speed and wind direction (at 10 m), temperature, humidity, solar radiation and rainfall.

In June 1996 these three meteorological stations were replaced by a single meteorological station referred to as AWS which is located to the south-east of the plant (see Figure 9.1). The older stations are to be decommissioned and are currently only being used to provide backup information. The Sandhill station has already been decommissioned. Table L.3 summarises the meteorological data collected to date, which provide a short-term view of the climatic conditions in the area.

Table L.3 Summary of atmospheric measurements, Olympic Dam 1980–95[1]

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Temperature (°C)													
mean maximum	36.1	35.9	32.6	27.2	22.3	18.3	18.1	20.1	24.3	28.3	31.7	34.2	27.4
mean minimum	19.8	19.9	17.6	12.5	9.1	5.2	4.3	8.6	8.6	12.7	15.7	18.6	12.5
Average humidity (%)	34.8	34.8	36.5	45.0	61.0	68.4	61.5	53.2	46.3	38.5	34.7	37.9	46.1
Mean wind speed at 10 m (m/s)	4.0	3.9	3.6	3.2	2.9	2.8	3.0	3.5	3.9	4.2	4.2	4.2	3.6
Average barometric pressure (hPa)	1001.7	1001.8	1006.5	1010.3	1011.8	1012.9	1011.3	1011.0	1008.6	1005.6	1003.7	1001.4	1007.2
Average solar radiation (W/m²)	294.6	265.4	225.5	176.4	121.8	101.4	114.6	146.9	195.2	243.4	278.5	277.0	203.4
													Total
Rainfall (mm)	13.5	20.7	32.9	5.4	20.4	15.7	10.4	12.9	9.9	17.0	11.6	29.3	**199.7**[2]
Evaporation (mm)	396.8	328.1	298.1	186.7	113.5	84.5	88.5	121.5	186.8	274.0	331.7	377.3	**2787.5**

1 *Temperature, rainfall and evaporation data recorded at the Main Gate Station. All other data except wind speed recorded at Sandhill. Wind speed recorded at Roxby Downs.*

2 *Rainfall includes data from two very wet years. The long-term annual average for the area is approximately 160 mm (Bureau of Meteorology 1988).*

L4.2 Review of dispersion meteorology

L4.2.1 Wind

In Chapter 9, Figure 9.2 presents seasonal and annual wind roses for the Olympic Dam area for 1993 which is the year for which most valid data are available (99.7% data recovery, or 8,736 valid hours of data). Annually the most common winds are from the south and south-south-east (SSE). These two sectors account for approximately 32% of all winds.

In summer the most common wind direction is SSE which accounts for approximately 24% of winds. In autumn the pattern of winds is similar with the most common direction being south, accounting for approximately 17% of winds. During winter, winds are common both from the south and the north. Southerly winds account for approximately 13% of winds whereas those from the north account for 8% and north-north-east for approximately 12%. During spring the southerlies are again the most common winds, but winds also occur with significant frequency from the northerly directions.

The annual average surface (10 m monitoring height) wind speed for 1993 was 3.8 m/s. This compares with the average for the years 1980–95 of 3.6 m/s (Table L.3). Given this pattern of winds it would be preferable to locate any future air quality monitors towards the north of the plant rather than the south.

L4.2.2 Atmospheric stability

Atmospheric stability is the parameter which controls the rate at which a plume will disperse in the atmosphere. In the modelling work presented later a conventional Gaussian dispersion model has been used to predict ambient ground-level concentrations of emissions. The model requires that for each hour for which dispersion is to be simulated, the stability of the atmosphere is specified in one of six stability categories, from A to F.

Stability class A refers to strongly convective conditions which will occur when the sun is high above the horizon and winds are light. Stability class D refers to neutral dispersion conditions when mechanical turbulence dominates the dispersion process. These conditions occur, either when the wind is strong, or when the cloud cover is such as to prevent significant solar heating of the ground thereby suppressing convection. Stability class F relates to stable conditions where vertical movement of the air is inhibited. Generally stable conditions occur on clear nights when the ground loses heat rapidly by radiation to space. Under these conditions the ground cools rapidly and chills the air close to it creating a stable condition with cool air near the ground and warmer air above for the Olympic Dam area.

Table L.4 summarises the frequency of occurrence of the six different stability classes found for the Olympic Dam area. Atmospheric stability is a derived parameter and can be determined in a number of ways depending on the available data. For the current study, stability has been determined by a scheme specified by the US EPA (1986) in which stability class is assigned on the basis of measurements of the standard deviation of wind direction (sigma-theta), wind speed and time of day or night.

Table L.4 Frequency of occurrence of Pasquill stability classes for 1993

Stability	Stability description	Standard deviation of wind direction (degrees)*	Occurrence (%)
A	Very unstable	25	10.5
B	Moderately unstable	20	4.7
C	Slightly unstable	15	8.4
D	Neutral	10	45.8
E	Slightly stable	5	23.7
F	Moderately stable	2.5	6.7

* *Measured at a height of 10 m.*

L4.2.3 Mixing height

In dispersion modelling the term 'mixing height' refers to the depth of the atmosphere from the ground to a limit normally 1–2 km above the surface through which pollutants will be mixed. Mixing height is determined by mechanical turbulence and convection. Mechanical turbulence is generated by the wind blowing over rough ground which creates turbulence that extends to a height above the ground determined by the strength of the wind and the shape and size of roughness elements (e.g. vegetation, buildings) on the surface.

Convectively determined mixing heights depend on the amount of heat energy transferred to the atmosphere during the day and the early morning temperature structure of the atmosphere into which the heat energy is injected.

The current study has estimated mixing height using a procedure developed by Powell (1976) for daytime conditions and a procedure suggested by Venkatram (1981) for night time conditions. Powell's scheme requires estimates of the maximum mixing height that will be reached during the day and works by fitting a quasi sinusoidal curve to the value of this maximum to determine the mixing height that will apply hour by hour during daylight.

For this study the maximum mixing heights used have assumed that in winter the maximum will be 1,000 m, in spring and autumn 1,200 m and in summer 1,500 m. These values may slightly underestimate the true mixing heights reached in the Olympic Dam area, but this will lead to a conservative assessment of air pollutant concentrations due to emissions from the plant. Table L.5 summarises the values of mixing height for the year by hour of day.

Table L.5 Number of hours during which mixing height lay within the indicated height range in 1993

Time	0 to 100 m	101 to 200 m	201 to 400 m	401 to 800 m	801 to 1,600 m	1601 to 3,200 m	>3,200 m
1	11	37	40	99	165	12	0
2	7	50	6	99	195	7	0
3	0	56	32	32	241	3	0
4	0	1	55	64	242	2	0
5	5	23	8	91	221	16	0
6	7	27	5	35	276	14	0
7	6	29	14	8	289	18	0
8	10	42	9	17	255	30	1
9	16	61	11	12	233	31	0
10	23	71	17	19	205	29	0
11	32	87	21	23	176	25	0
12	33	113	21	21	153	23	0
13	24	119	16	27	159	18	1
14	33	140	16	25	131	19	0
15	25	180	11	25	117	5	1
16	29	129	79	36	84	7	0
17	33	153	17	94	49	18	0
18	42	145	38	57	62	20	0
19	60	95	51	80	57	21	0
20	52	76	47	81	83	25	0
21	46	64	70	82	73	29	0
22	18	78	70	72	105	21	0
23	11	54	74	73	136	16	0
24	10	66	10	129	135	14	0

L4.2.4 Temperature

Ambient temperature is required by the dispersion model to determine plume rise. The temperature used in the modelling studies was that measured at the Sandhill station. Table L.3 summarises the mean maximum and mean minimum temperatures that were recorded at the site on a monthly basis.

L4.3 Air quality monitoring programmes

Air quality monitoring programmes have been established to measure concentrations of sulphur dioxide, total suspended particulate matter (TSP) and dust deposition levels. The results of these monitoring programmes are discussed below.

L4.3.1 Dust

High volume sampler monitoring programme

A series of eight high volume dust samplers are located across the mine and lease area. The samplers are operated on a weekly basis, and thus no 24-hour concentration data are available.

The eight sites at which monitoring takes place are referred to as SBS, NTS, ODV, NBS, Sandhill, Desal, Admin and TAS. These are shown in Chapter 10, Figure 10.21. At the end of each four-week period, the samples are aggregated and a monthly average total dust concentration (measured as TSP) is determined.

An analysis of the results is available for the year from March 1993 to February 1994. The data show that the monitor site experiencing the highest dust concentrations was that located at Sandhill. Monthly average concentrations reached peak levels of approximately 66 $\mu g/m^3$ in January 1994. The average of all high volume sampling results was 32 $\mu g/m^3$. This annual average level is well below the 90 $\mu g/m^3$ level recommended as the annual average limit by the NHMRC.

Measurements have also been made to determine the approximate relationship between TSP and PM_{10} concentrations. The PM_{10} fraction of TSP was found to be approximately 50% of the total dust collected. This result is consistent with values found in other non-urban areas where mining, quarrying and agricultural activities are the dominant sources of the particles. Where combustion processes are the dominant sources, finer particles comprise a higher percentage.

Dust deposition (fallout)

Dust deposition is measured at a network of gauges at forty-nine sites. Dust deposition is reported monthly. The results show that during 1993–94 high levels of dust fallout occurred in areas close to the plant and tailings retention system. The highest average recorded level for TA7, TA8, P8 and TAS (see Figure 10.21) was 39 g/m^2 per month (1.3 g/m^2 per day).

Dust fallout levels are related to dust concentrations in a complex way depending on particle sizes and dispersion conditions. It is relevant to note that fallout levels are primarily an indicator of the potential for nuisance impacts. They do not necessarily indicate the existence or severity of an air quality impact. For example, within an area where intensive earthworks are being undertaken, where land is being tilled, or near unsealed roads, dust deposition levels can be very high, but impacts are not significant. Impacts become significant if the affected land is being used for a dust sensitive use such as housing, spray painting, cut-flower production, etc.

The only relevant dust monitoring site that might be useful in assessing if nuisance impacts are occurring are the two sites referred to as ODV and ODVE, which are located near the southern boundary of the Special Mining Lease in the Olympic Dam Village area. This area records long-term average deposition levels of approximately 0.08 g/m^2 per day, or 2.4 g/m^2 per month. This can be compared with the NSW EPA goal (used as a reference by the SA EPA) which considers that amenity is affected when the annual average dust fallout levels reach 4 g/m^2 per month on an annual basis (State Pollution Control Commission 1983; Dean et al. 1990). The results for ODV and ODVE indicate that dust levels in residential areas are at acceptable levels.

L4.3.2 Sulphur dioxide

Sulphur dioxide concentrations are monitored at the slag concentrator site approximately 1.5 km south of the main existing sources of sulphur dioxide, which are the acid plant and smelter. As noted in Section L4.2.1 this site is probably not representative of the areas receiving the greatest impact from the current emissions of sulphur dioxide from the plant.

Analysis of recently available monitoring data shows that sulphur dioxide concentrations are generally extremely low, but occasionally reach high peak levels. There have been a number of occurrences where SO_2 concentrations have exceeded the previous 1-hour goal of 700 µg/m^3 (now revised to 570 µg/m^3) and the previous 10-minute goal of 1,400 µg/m^3 (now revised to 700 µg/m^3). These occurrences are associated with upset conditions in the metallurgical plant. Data for three selected months—January, March and May—are typical of variation in SO_2 concentrations at this site (see Figure L.1). The plots show long periods with no measurable, or very low, concentrations of sulphur dioxide followed by brief periods in which concentrations may reach high levels.

Monthly average sulphur dioxide concentrations for the year March 1993 through to February 1994 are summarised in Table L.6. It can be seen that the annual average concentration at this site is 5.5 µg/m^3 which can be compared with the air quality goal of 60 µg/m^3. The monitoring thus indicates that long-term average levels of sulphur dioxide are well within limits, but that short-term air quality goals may be exceeded occasionally.

Table L.6 Monthly average SO_2 concentrations at slag concentrator, µg/m^3

March 1993	7.1
April	2.8
May	11.9
June	3.6
July	5.2
August	5.9
September	2.9
October	12.8
November	2.1
December	3.0
January 1994	6.0
February	2.1
Year	**5.5**

L4.3.3 Odour

No odour monitoring is undertaken and it is clear that there is no potential for residential areas to be affected by odour from the mine or plant operations. The principal odour emissions from the plant are those of xanthates used in the flotation process. In the daytime, odours are easily detected within a few hundred metres downwind of the source. At night-time it is likely that odours would be detected over significantly greater distances, but at no

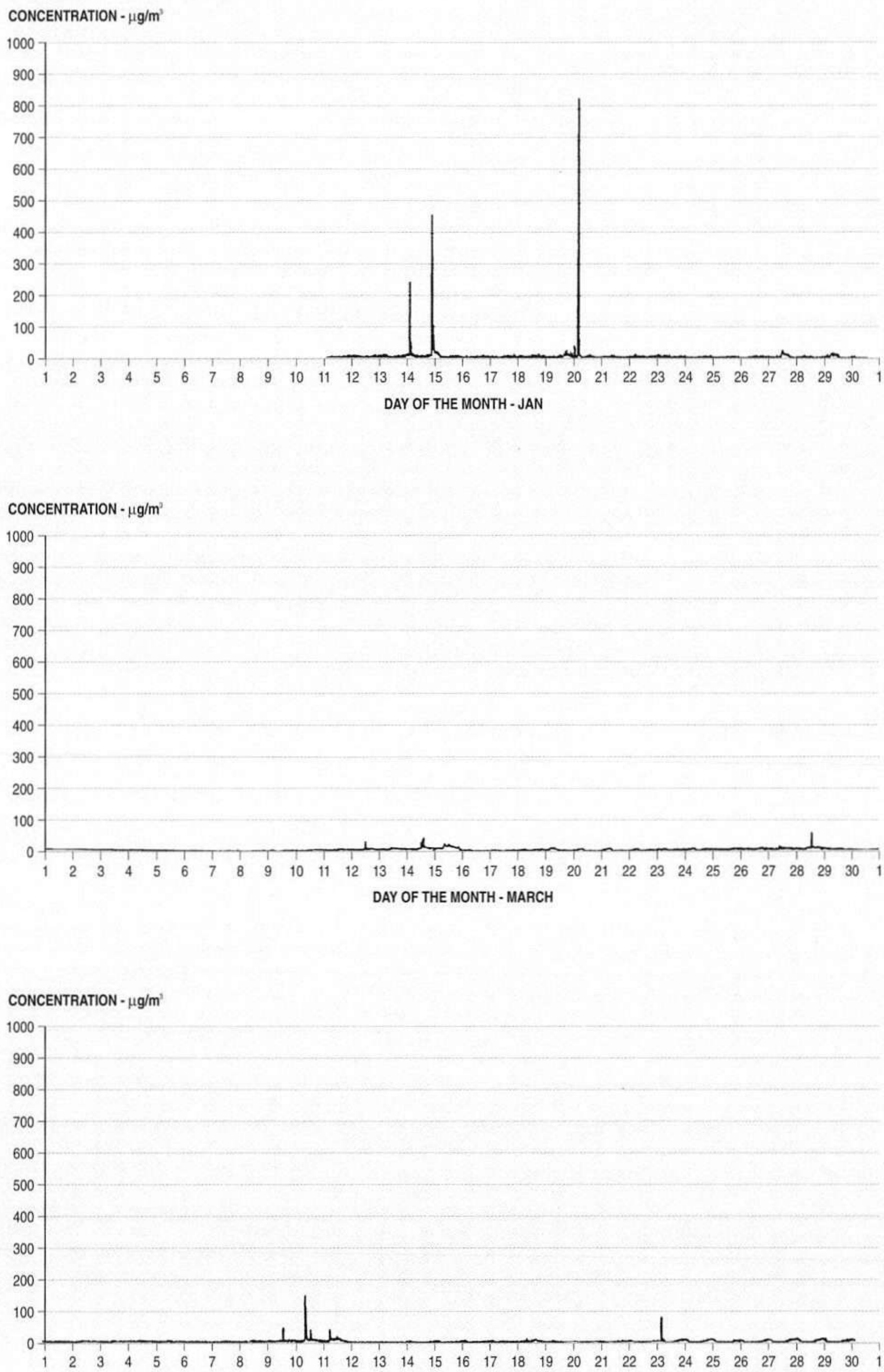

FIGURE L.1

EXAMPLES OF MONITORED 10-MINUTE SULPHUR DIOXIDE CONCENTRATIONS AT THE SLAG CONCENTRATOR SITE

time are the residential areas likely to experience odours and there is no requirement for further analysis of odour dispersion.

L5 EMISSIONS—EXISTING AND FUTURE

L5.1 Normal operations

The existing and proposed operations at Olympic Dam result, or will result, in emissions from a number of sources as follows:

- dust (TSP, PM_{10} and $PM_{2.5}$) from the handling of ore, waste, backfill material and smelter operations
- oxides of nitrogen (NO_x) from motor vehicles, gas-fired boilers, standby generators and the smelting process
- SO_2 from the smelting processes, acid plants and calciner
- CO from motor vehicles and the smelting process, emitted from the acid plant
- HF from the smelting process.

While all of these emissions will contribute to the burden of pollutants in the vicinity of the mine and processing plant, it is clear that some of the emissions are of little environmental significance and do not require a detailed analysis. For example, the ore has a high moisture content and dust from the handling of ore has not proved to be a significant problem in the past. The moisture levels remain high in the autogenous mill and subsequent milling stages and the remaining flotation stages are undertaken using slurried material. Fugitive dust emissions are negligible.

The quarry, which is operated to provide backfill for the mine, generates dust; however the remoteness of the site and quantities of dust generated are not significant enough to justify a detailed analysis of dust dispersion. Thus, except for assessing radiological impacts, which is done in Chapter 10 of the main report of the EIS, no detailed assessment of fugitive dust dispersion is undertaken here and monitoring programmes are relied upon to verify that no significant impacts are occurring.

Other minor emissions include sulphur dioxide from the calciner and oxides of nitrogen from motor vehicles and the occasional use of the standby generators which provide emergency power should the mains supply be cut. The calciner gases are scrubbed, and SO_2 emissions are estimated to be 0.022 g/s for 200,000 t/a copper production, and 0.038 g/s for 350,000 t/a copper production. These minor emission sources have not been included in the modelling.

The emission sources that have been analysed in detail because of their potential to cause adverse effects are those from the smelter and acid plant. The emissions considered are: SO_2, NO_2, particulate matter (TSP, PM_{10} and $PM_{2.5}$), HF and CO. The relevant particulate matter criteria are TSP, PM_{10} and $PM_{2.5}$. In this assessment, all of the stack particulate emissions are assumed to be PM_{10}, and thus the PM_{10} criteria are used as reference values.

A number of different development cases have been considered as follows:

1 the existing smelter and acid plant

2 a new plant producing 200,000 t/a copper, operating with the existing smelter and acid plant decommissioned

3 a 285,000 t/a plant comprising a new 200,000 t/a copper plant using a mixture of imported concentrate and concentrate produced on site, operating with the existing plant (with modified air pollution controls–see later) producing 85,000 t/a copper from concentrate produced on site

4 a 350,000 t/a copper plant comprising the 200,000 t/a plant and a possible new 150,000 t/a copper plant based on a new matte smelter, and with the existing plant decommissioned.

These four cases consist of three plants operated in four different combinations. At any one time only one or two plants would operate.

The basic emission conditions for each of the three plants are summarised in Tables L.7 to L.9. These tables summarise all the emission information required for the modelling of routine emissions from the plant, with the exception of the building-wake information. The emission rates for SO_2 in Tables L.7 to L.9 represent the highest hourly emission rates expected under routine operating conditions. Other non-routine conditions are discussed later.

Building-wake effects have been assessed using the US EPA's (1993) Building Profile Input Program (BPIP). This program accepts information about the dimensions of the buildings within the plant and determines which buildings will affect which stacks. The output of the BPIP is a file which is incorporated into the ISC3-ST input file which allows the interaction between building-induced turbulence and the dispersing plume to be determined for each of 36 wind directions.

Because of the heights (90 m—see Tables L.8 and L.9) and locations of the new smelter and acid plant stacks for the expansion options relative to the heights and positions of the associated buildings, the effects of building wakes on the dispersion are expected to be minor. However, for the current plant, where stacks are short relative to the adjacent buildings, building wake effects are significant (Table L.7).

There is an important difference between the way in which the existing plant operates and the way that the proposed expanded plants will operate. Anode furnace gases from the proposed plants will be directed to the acid plant where sulphur is removed before discharge to the atmosphere through a 90 m stack. In the existing plant, gases from the two anode furnaces are discharged directly to atmosphere through 60 m stacks which service the two anode furnaces.

Anode furnace emissions vary significantly with time. The initial phase is referred to as the 'oxidation' phase. For modelling purposes this phase has been assumed to last for three hours. Sulphur dioxide emissions are highest in the first hours. Based on emissions measured by Amdel (1994) the maximum hourly average SO_2 emission rate is estimated to be 200 g/s. For the second and third hours the average emission rate is estimated to be 50% and 10% of the maximum value, respectively. The remaining phases in the anode furnace cycle, namely 'holding' and 'reducing', result in much lower emissions of SO_2. Again based on Amdel (1994) data the emission rate is taken to be 1.5 g/s. Volume flow rates for all cases have been taken to be 50,000 Nm^3/h and the temperature for oxidation has been taken to be 196°C for 'oxidation' and 'holding' and 181°C for the reducing phase.

The two furnaces operate so that they are never both in the 'oxidation' phase simultaneously. To simulate this in the model the emissions were assumed to vary hour by hour so that the three-hour oxidation cycle occurred three times every 24 hours, with each cycle lasting three hours. For convenience in modelling only one of the stacks was assumed to be servicing the anode furnaces in 'oxidation' mode. In practice of course both furnaces cycle between the 'oxidation', 'holding' and 'reducing' modes. This is done because it allows the model to keep the same exit velocity and exit temperature for each stack. The two anode furnace stacks are close together and are otherwise identical so this assumption will have no significant effect on the predicted ground-level concentrations and it allows the number of stacks used in the model to be kept to a minimum.

Ambient air quality goals have been revised since the plant was constructed. The expanded plant will need to comply with these more stringent goals and the existing plant will need to be upgraded to achieve compliance. The options considered are discussed in Section L7.1. Table L.7 summarises the emissions that have been assumed will apply for the existing plant post-expansion.

Table L.7 Emission data used in the model for the existing smelter and acid plant at present and post-expansion (the latter in parentheses if altered)

Stack	Easting (E) Northing (N)	Stack height (m)	Stack internal diameter at tip (m)	Gas flow (Nm^3/h)	Exit velocity (m/s)	Exit temp. (°C)	Emission (g/s)				
							SO_2	NO_x	CO	HF	PM
Existing anode furnace No. 1 stack (oxidising)	679169E 6630054N	60 (80)	1.37	655,740	19.10 (12.11)	196 (80)	300.4[1] (45.1)	0.155	0.5	–	0.4
Existing anode furnace No. 2 stack (reducing)	679139E 6630054N	60 (80)	1.37	655,740	19.10 (21.11)	181 (80)	1.53[1]	0.155	0.5	–	0.4
Existing acid plant stack	678970E 6630106N	40 (70)	1.80	108,240	6.00	80	5.7	–	–	0.13	–

1 *Varies depending on the phase of the anode furnace cycle (see text for discussion).*

Table L.8 Emission data used in the model for 200,000 t/a copper production smelter and acid plant

Stack	Easting (E) Northing (N)	Stack height (m)	Stack internal diameter at tip (m)	Gas flow (Nm^3/h)	Exit velocity (m/s)	Exit temp. (°C)	Emission (g/s)				
							SO_2	NO_x	CO	HF	PM
Flash smelter stack	678637E 6630103N	90	3.86	655,740	17.90	53	52.04	0.73	2.3	–	1.9
Acid plant No. 2 stack	678737E 6630108N	90	1.70	108,240	17.08	79	12.69	–	–	0.30	–

1 *Varies depending on the phase of the anode furnace cycle (see text for discussion).*

Table L.9 Emission data for 350,000 t/a copper production smelters and acid plants

Stack	Easting (E) Northing (N)	Stack height (m)	Stack internal diameter at tip (m)	Gas flow (Nm^3/h)	Exit velocity (m/s)	Exit temp. (°C)	Emission (g/s)				
							SO_2	NO_x	CO	HF	PM
Flash smelter stack	678637E 6630103N	90	3.86	655,740	17.90	53	52.04	0.73	2.3	–	1.9
Acid plant No. 2 stack	678737E 6630108N	90	1.70	108,240	17.08	79	12.69	–	–	0.30	–
Matte smelter stack	678451E 6630127N	90	3.34	491,805	17.90	53	39.03	0.42	1.7	–	1.4
Acid plant No. 3 stack	678451E 6630132N	90	1.47	81,180	17.08	79	9.52	–	–	0.23	–

L5.2 Upset conditions

As well as emissions under routine operating conditions the acid plants will emit higher concentrations for the first few hours (approximately four hours) following start-up and during some upset operating conditions.

During start-up the concentration of SO_2 in the acid plant tail gas (expanded plant) will average no more than 2,000 p.p.m. (5.71 g/Nm^3) in the first two hours falling to less than 1,000 p.p.m. (2.86 g/Nm^3) in the next two hours and reaching design after four hours. This corresponds to an emission rate of 172 g/s averaged over the first hour.

Upset conditions can occur occasionally (estimated to be eight hours per year) when smelter gases at 1,340°C cannot be handled by the waste heat boiler and cannot be passed to the acid plant. Under this emergency condition gases are discharged directly from the smelter furnace 90 m stack. The worst-case SO_2 emission rate is estimated to be 3,772 g/s and the temperature of the emission is estimated to be 138°C. In estimating this temperature it is assumed that all other gas flows are maintained at their normal values so the high temperature smelter gases at 1,340°C are cooled significantly by mixing with other gases in the stack.

L6 APPROACH TO IMPACT ASSESSMENT

The basic approach used for impact assessment is summarised below:

1 analysis of the proposal and various options to identify and quantify emissions of pollutants

2 identification of appropriate air quality goals to protect ambient air quality

3 the characterisation of the dispersion conditions in the area and the preparation of an hourly meteorological data file suitable for use with a computer-based dispersion model

4 the use of a computer-based dispersion model (ISC3-ST) with local meteorological data and appropriate emission data to predict ground-level concentration of emissions for a number of potential development options

5 the comparison of the predicted ground-level concentrations with the air quality goals.

The above steps define the main components of the assessment procedure. A critical component of the assessment is the use of the ISC3-ST model. The user instructions for the model are provided in documentation prepared by the US EPA (US EPA 1995A, and US EPA 1995B). The main relevant features of the model are summarised below.

The ISC3-ST model includes a wide range of options for modelling air quality impacts of pollution sources. Only those relevant to or of interest for the current study are noted.

The ISC3-ST model has been designed to support the US EPA's regulatory modelling programmes; the regulatory modelling options, as specified in the Guideline on Air Quality Models (Revised) (US EPA 1986), are the default mode of operation for the models. These options include the use of stack-tip downwash, buoyancy-induced dispersion, final plume rise (except for sources with building downwash), a routine for processing averages when calm winds occur, default values for wind profile exponents and for the vertical potential temperature gradients, and the use of upper bound estimates for large, squat buildings having an influence on the lateral dispersion of the plume.

The user can easily ensure the use of the regulatory default options by selecting a single keyword on the modelling option input card. To maintain the flexibility of the model, the non-regulatory default options have been retained, and by using descriptive keywords to specify these options it is evident at a glance from the input or output file which options have been employed for a particular application.

The user may select either rural or urban dispersion parameters, depending on the characteristics of the source location. The model is capable of handling multiple sources, including point, volume, area and open pit source types.

The model has considerable flexibility in the specification of receptor locations. The user can specify multiple receptor networks in a single run, and may also mix Cartesian grid receptor networks and polar grid receptor networks in the same run. The basic types of printed output available with the Short Term model are:

1 Summaries of high values (highest, second highest, etc.) by receptor for each averaging period and source group combination

2 Summaries of overall maximum values (e.g., the maximum 50) for each averaging period and source group combination

3 Tables of concurrent values summarised by receptor for each averaging period and source group combination for each day of data processed.

L7 MODEL PREDICTIONS AND ASSESSMENT OF IMPACTS

As indicated above, impacts have been assessed for significant emissions using the ISC3-ST model with meteorological data from the Sandhill monitoring station with estimated emissions for each of four potential operating cases. Significant emissions have been taken to be those of SO_2, NO_x, CO, HF and particulate matter (assumed to be PM_{10}) from the smelter and acid plant stacks.

The results for SO_2 predictions have been presented as contour plots and in tabular form, and for all other cases in tabular form only. The tabulated results are the most useful for checking for compliance with relevant air quality goals. The contour plots illustrate the pattern of pollutant dispersion showing the areas most likely to be affected by emissions, but tend to smooth the peaks and low points of the predicted concentrations. Consequently, the tables are better for determining the highest concentrations.

In each case, the contour plots have been prepared from predictions made at points in two nested grids. The first grid uses a 100 m spacing for grid points and covers a square area, 2 km on a side. The SW corner of the grid is at coordinate 678000 m East and 6629000 m North. The second grid uses a spacing of 1 km and covers a square area of 20 km on a side with the SW corner at 669000 m East and 6620000 m North.

The model is used to estimate the highest concentrations that occur over the year at each grid point. The contour plots have been prepared from these predicted values. Thus the plots do not show the dispersion pattern that applies at a particular hour or day, but they are a composite showing the highest concentrations that are estimated at any time in the year. The results of all model runs are summarised in Tables L.10 to L.16.

Contour plots showing the dispersion patterns of SO_2 for 10-minute, 1-hour and 1-year averaging periods for each of the four cases are provided in Chapter 9, Figures 9.3 to 9.5. It should be noted that the contour intervals have been varied so that a readable figure is obtained.

The significance of the results for each of the four cases is discussed in Sections L7.1 to L7.4.

The entries in Tables L.10 to L.16 are written to one decimal place. This is done to allow comparison between different cases. It does not indicate the accuracy with which predictions are made. Model predictions will at best be accurate to ±40% and may be less accurate in many cases.

It should also be noted that ISC3-ST can only predict 1-hour average concentrations. The 10-minute averages have been estimated by assuming that they will be 43% higher than the 1-hour averages. This assumes a 0.2 power law variation in concentration with averaging time. This is a widely used approach in dispersion modelling when detailed turbulence structure information is not available.

Table L.10 Predicted highest, second highest and third highest SO_2 concentrations for different development cases, µg/m³

SO_2 concentration	Case 1 existing 85,000 t/a	Case 2 200,000 t/a	Case 3 285,000 t/a	Case 4 350,000 t/a	SA EPA air quality goal[1]
10-MINUTE					
Highest	2,026.5	311.8	693.4	527.2	700
Second highest	1,579.7	303.2	672.1	439.6	
Third highest	1,561.3	298.2	659.5	434.2	
1-HOUR					
Highest	1,417.1	218.1	484.9	368.7	570
Second highest	1,104.7	212.0	470.0	307.4	
Third highest	1,091.8	208.5	461.2	303.6	
ANNUAL					
Highest	17.6	7.0	9.8	11.8	60
Second highest	17.5	6.2	8.8	11.2	
Third highest	17.1	6.2	8.7	11.1	

1 *Sulphur dioxide goals were recently revised from 1,400 µg/m³ (10-minute) and 700 µg/m³ (1-hour).*

Table L.11 Predicted highest and second highest SO_2 concentrations for different development cases at the closest residential area (Olympic Dam Village), µg/m³

SO_2 concentration	Case 1 existing 85,000 t/a	Case 2 200,000 t/a	Case 3 285,000 t/a	Case 4 350,000 t/a	SA EPA air quality goal[1]
10-MINUTE					
Highest	755.9	97.1	277.6	157.2	700
Second highest	668.2	84.1	241.0	151.3	
1-HOUR					
Highest	528.6	67.9	194.1	109.9	570
Second highest	467.3	58.8	168.5	105.8	
ANNUAL	2.2	0.4	1.1	0.7	60

1 *Sulphur dioxide goals were recently revised from 1,400 µg/m³ (10-minute) and 700 µg/m³ (1-hour).*

Table L.12 Predicted highest and second highest CO concentrations for different development cases, µg/m³

CO concentration	Case 1 existing 85,000 t/a	Case 2 200,000 t/a	Case 3 285,000 t/a	Case 4 350,000 t/a	SA EPA air quality goal
15-MINUTE					
Highest	262.5	19.7	262.5	26.9	–
Second highest	100.3	17.7	100.3	20.8	
1-HOUR					
Highest	198.9	14.9	198.9	20.4	40,000
Second highest	76.0	13.4	76.0	15.8	
8-HOUR					
Highest	25.5	6.5	25.7	8.7	10,000
Second highest	16.7	4.7	16.7	7.1	

Table L.13 Predicted highest and second highest NO_x concentrations for different development cases, μg/m³

NO_X concentration	Case 1 existing 85,000 t/a	Case 2 200,000 t/a	Case 3 285,000 t/a	Case 4 350,000 t/a	SA EPA air quality goal
1-HOUR					
Highest	49.7	4.5	49.7	6.1	320
Second highest	19.0	4.1	19.0	4.7	

Table L.14 Predicted highest and second highest HF concentrations for different development cases, μg/m³

HF concentration	Case 1 existing 85,000 t/a	Case 2 200,000 t/a	Case 3 285,000 t/a	Case 4 350,000 t/a	ANZECC criteria
12-HOUR					
Highest	2.32	0.63	2.43	0.93	3.7
Second highest	1.67	0.51	1.67	0.82	
24-HOUR					
Highest	1.45	0.48	1.45	0.66	2.9
Second highest	0.99	0.42	0.99	0.62	
7-DAY					
Highest	0.99	0.33	0.99	0.45	1.7
Second highest	0.67	0.29	0.67	0.42	
30-DAY					
Highest	0.12	0.15	0.16	0.25	0.84
Second highest	0.08	0.11	0.12	0.21	
90-DAY					
Highest	0.10	0.12	0.13	0.20	0.5
Second highest	0.06	0.09	0.10	0.17	
ANNUAL					
Highest	0.05	0.07	0.08	0.13	–
Second highest	0.04	0.06	0.08	0.12	

Note: 7-day and 90-day averages estimated from 24-hour and 30-day averages, respectively, using the 0.2 power law.

Table L.15 Predicted highest and second highest PM_{10} concentrations for different development cases (due to stack emissions), μg/m³

PM_{10} concentration	Case 1 existing 85,000 t/a	Case 2 200,000 t/a	Case 3 285,000 t/a	Case 4 350,000 t/a	USEPA standard
1-HOUR					
Highest	7.5	6.9	11.3	11.7	–
Second highest	7.0	5.8	8.9	8.8	
24-HOUR					
Highest	2.4	1.4	2.4	1.9	150
Second highest	2.0	1.3	2.0	1.7	
ANNUAL					
Highest	0.23	0.16	0.25	0.28	50
Second highest	0.23	0.15	0.25	0.28	

Table L.16 Predicted highest and second highest SO_2 concentrations for the first hour of acid plant start-up, μg/m³

SO_2 concentration		SA EPA air quality goal[1]
10-MINUTE		
Highest	1,588.3	700
Second highest	1,523.8	
1-HOUR		
Highest	1,110.7	570
Second highest	1,065.6	

1 *Sulphur dioxide goals were recently revised from 1,400 μg/m³ (10-minute) and 700 μg/m³ (1-hour).*

L7.1 Case 1—Existing case

This case represents existing conditions in which copper production is approximately 85,000 t/a. The emission conditions used in the model are summarised in Table L.7, which should be read in conjunction with the discussion on the way in which varying emissions from the anode furnace occur. The results are summarised in Tables L.10 to L.15. Contour plots showing the pattern of SO_2 dispersion for these results are presented in Figures 9.3(a), 9.4(a) and 9.5(a). It can be seen that under routine operating conditions the model predicts that some exceedances of the 10-minute and 1-hour goals are likely within the Special Mining Lease. Exceedance of the 10-minute goal is predicted to occur once per year at Olympic Dam Village. All other goals for SO_2 are predicted to be met for routine operating conditions.

Two matters should be noted with respect to the existing plant. The first is that the air quality goals have been made significantly more stringent since the plant was commissioned and secondly the number of exceedances of the short-term goals will depend on the conjunction of unfavourable dispersion conditions with the operation of the anode furnaces in the early phases of oxidation when emissions of SO_2 are at their highest.

The general design philosophy for the expanded plant is to set stack heights and emission levels so that exceedances are not predicted even under the most unfavourable dispersion conditions expected in the course of a year. This necessitates the redesign of the existing plant so that if it is used as part of the Case 3 development (285,000 t/a) the air quality goals will be met within the Special Mining Lease as well as outside it.

The envisaged treatment to do this involves scrubbing to remove 85% of the sulphur (the maximum readily achievable level) and increasing the anode furnaces stack height to 80 m and the acid plant stack height to 70 m. The scrubbing process reduces the temperature of the emission which decreases the buoyancy and the plume rise of the emission. Increased stack heights are needed to overcome this effect.

These upgrades, or programmes producing equivalent results, would be implemented if the Case 3 development, assessed in Section L7.3, is implemented.

Under acid plant start-up and upset operating conditions, emissions of SO_2 would be higher than those used in the model and consequently the predicted ground-level concentrations may be significantly higher for the occasions when these apply. An exemption under the SA EPA Act licence applies to these operating conditions, which occur only a few times per year.

Ground-level concentrations of other stack emissions (CO, NO_x, HF and particulate matter, PM_{10}) all comply with the relevant air quality goals.

L7.2 Case 2—200,000 t/a copper production

Case 2 relates to emissions from the proposed expanded plant operated in isolation. Copper production will be approximately 200,000 t/a. The emission conditions used in the model are summarised in Table L.8. The results are summarised in Tables L.10 to L.15. Contour plots showing the pattern of SO_2 dispersion for these results are presented in Figures 9.3(b), 9.4(b) and 9.5(b). It can be seen that under routine operating conditions the model predicts that ground-level concentrations will comply with all air quality goals.

Under start-up operating conditions, acid plant emissions of SO_2 would be higher than those used in the model and consequently the predicted ground-level concentrations may be significantly higher for the occasions when these apply (Table L.16). Higher than normal emissions apply for the first few hours of operation. The predicted highest and second highest 1-hour ground-level concentrations are 1,111 $\mu g/m^3$ and 1,066 $\mu g/m^3$, respectively, for the first hour of operation. These are above the SA EPA's goals. An exemption under the SA EPA Act licence would be sought for these operating conditions, which would occur only a few times per year. If start ups are timed for favourable dispersion conditions it should still be possible to comply with the SA EPA ambient goals.

Ground-level concentrations of other stack emissions (CO, NO_x, HF and particulate matter, PM_{10}) all comply with the relevant air quality goals.

L7.3 Case 3—285,000 t/a copper production

Case 3 represents the proposed expanded smelter and acid plant operated simultaneously with the existing acid plant and smelter to produce 285,000 t/a of copper. This case would involve the importation of concentrate from other sources and as discussed earlier it would involve changes to air pollution controls on the anode furnace emissions.

The emission conditions used in the model are set out in Tables L.7 and L.8.

The results are summarised in Tables L.10 to L.15. Contour plots showing the pattern of SO_2 dispersion for these results are presented in Figures 9.3(c), 9.4(c) and 9.5(c). Under routine operating conditions the model predicted that ground-level concentrations would comply with all air quality goals using the existing stack configuration except those for SO_2. The model was then run using alternative stack configurations for the existing plant and scrubbing of anode furnace emissions to ensure compliance with the SA EPA goals. These stack heights are 80 m for the anode furnaces and 70 m for the acid plant. Anode furnace emissions would be scrubbed to remove 85% of sulphur emissions in the oxidation phase.

It should be noted that the above is only one option that could be pursued. Other options could include different control technology or process alternatives. However, the modelling exercise has demonstrated that compliance with the SA EPA goals is readily achievable.

Again, under acid plant start-up conditions emissions of SO_2 would be higher than those used in the model and consequently the predicted ground-level concentrations may be significantly higher for the occasions when these higher emissions apply.

Ground-level concentrations of other stack emissions (CO, NO_x, HF and particulate matter, PM_{10}) all comply with the relevant air quality goals.

L7.4 Case 4—350,000 t/a copper production

Case 4 relates to emissions from the proposed expanded plant operated with a possible future matte smelter and acid plant located to the west of the proposed expanded plant. The combined copper production would be approximately possible future 350,000 t/a. The emission conditions used in the model are summarised in Tables L.8 and L.9. Emissions for the possible future 350,000 t/a plant have been derived by scaling the emissions from the proposed 200,000 t/a expansion plant. Stack heights, emission temperature and building dimensions have been assumed to stay the same. Stack diameters have been reduced for the matte smelter and acid plant No. 3 stacks to maintain the same exit velocities as for the proposed 200,000 t/a plant.

The results are summarised in Tables L.10 to L.15. Contour plots showing the pattern of SO_2 dispersion for these results are presented in Figures 9.3(d), 9.4(d) and 9.5(d). It can be seen that under routine operating conditions the model predicts that ground-level concentrations will comply with all air quality goals.

Under start-up conditions the predicted ground-level concentrations may be significantly higher. Higher than normal emissions apply for the first few hours of operation. The SA EPA's goals are predicted to be exceeded under these conditions, and an exemption under the SA EPA Act licence would need to be sought for these operating conditions, which would only occur a few times per year.

Ground-level concentrations of other stack emissions (CO, NO_x, HF and particulate matter, PM_{10}) all comply with the relevant air quality goals.

L8 CONCLUSIONS

This study has assessed air quality impacts expected for four potential expansion cases for the Olympic Dam project. The cases considered include the operation of the existing 85,000 t/a copper smelter and acid plant; the construction of a new 200,000 t/a copper plant comprising a new flash smelter and acid plant to be operated by itself with the existing smelter and acid plant shut down; the operation of the existing smelter and acid plant with the new flash smelter and acid plant to create a 285,000 t/a plant; and the construction of a new matte smelter and new acid plant to be operated together with the proposed 200,000 t/a copper flash smelter and acid plant to achieve an overall copper production rate of 350,000 t/a.

The model results indicate that the current plant may occasionally exceed the SA EPA's ambient air quality goals for SO_2 under routine operating conditions depending on dispersion conditions. The monitoring data also show that the goals are exceeded under some upset conditions.

The model results indicate that stack emissions under routine operating conditions from the proposed 200,000 t/a copper proposal are expected to comply with all SA EPA air quality goals for SO_2, NO_2, CO, HF and particulate matter.

For the proposed 285,000 t/a plant, under routine operating conditions the SA EPA goals can be met if the existing smelter and acid plant stacks are increased in height and the anode furnace emissions are scrubbed to remove 85% of the sulphur when the furnace is in oxidation mode.

For the proposed 350,000 t/a plant, under routine operating conditions all the SA EPA goals are predicted to be met.

Under acid plant start-up conditions for all options the SA EPA 10-minute and 1-hour goals for SO_2 could be exceeded for the first hour following start-up depending on the dispersion conditions at the time of start-up and an exemption under the SA EPA Act licence would need to be sought for this.

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APPENDIX M

ENVIRONMENTAL AND OCCUPATIONAL NOISE ASSESSMENT

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APPENDIX M

ENVIRONMENTAL AND OCCUPATIONAL NOISE ASSESSMENT

CONTENTS

M1 INTRODUCTION

Vipac Engineers & Scientists Ltd were engaged to carry out the Noise Assessment for the WMC Olympic Dam Expansion Project EIS.

This assessment has involved the review of the 1983 EIS, the description and assessment of the existing operations and two expansion horizons, initially 200,000 t/a copper and future possible capacity of 350,000 t/a copper.

The predicted impact of operations beyond the Olympic Dam operation site boundary is assessed against statutory environmental and industrial noise regulations (South Australian Government 1994; Standards Australia 1989). The expected impact on employees and other site personnel (e.g. maintenance workers, sub-contractors) is assessed relative to the Occupational Health, Safety and Welfare Regulations, 1995, Part 2 (OHSW 1995).

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M3 ENVIRONMENTAL NOISE ASSESSMENT

M3.1 Criteria

The statutory regulations set out in the Industrial Noise Policy (South Australian Government 1994) provide criterion limits in the form of maximum permissible noise levels for an existing development in a range of land use zones.

The township of Roxby Downs, located about 15 km to the south of the operations site, is classified as a predominantly residential area, which has a maximum permissible A-weighted equivalent noise level (L_{eq}) of 52 dBA during the day (7 a.m.–10 p.m.) and 45 dBA during the night (10 p.m.–7 a.m.). For a rural area, the limits are 47 dBA and 40 dBA for day and night respectively.

The operations plant itself and the area up to the site boundary of the Special Mining Lease are classified as a predominantly industrial zone, which has maximum permissible noise levels of 70 dBA during the day or night.

The AS1055 standard (Standards Australia 1989) provides a guideline for new developments. The A-weighted noise level exceeded for 10% of the time (L_{A10}) due to the development should not exceed the existing background level (L_{A90}) by more than 5 dBA, beyond the plant boundary.

M3.2 Methodology

M3.2.1 Overview

Using the existing plant operations as a baseline, the future expansion phases are investigated and any predicted impacts are identified and assessed against regulation criteria. Mitigation measures are investigated and recommended to ameliorate any significant environmental impacts.

The 1983 EIS results are reviewed and compared with existing operations (Vipac 1982).

Significant noise sources throughout the operations plant are identified and measured; the sound power level of each source is subsequently calculated. The plant physical details and source location and noise characteristics are built into a comprehensive computer noise model.

A verification of the methodology for the existing operating level (85,000 t/a copper production) is provided by comparison of measured and predicted noise levels at control points. The noise levels generated by the two phases of the expansion are predicted using the model. The ranking of major sources at control points is determined for each phase.

The predicted noise levels throughout the plant and beyond the site boundary are assessed relative to the environmental and industrial regulation requirements. Mitigation measures are investigated and recommended where required or appropriate.

M3.2.2 Modelling

The basic methodology involved in the noise model formulation includes the following steps:

- Definition of significant noise sources

  An audit of the primary equipment with significant noise generation characteristics was carried out for the three scenarios: existing baseline (85,000 t/a copper production), initial expansion (200,000 t/a copper production) and possible future expansion (350,000 t/a copper production). Estimates and/or measurements of their sound power were based on on-site measured data, 1983 EIS data, manufacturers' data or library references for actual plant installed, and newly acquired data on additional or proposed plant machinery/sources.

  Brief sound power measurements were carried out on-site using sound intensity and engineering sound power measurement methods generally in accordance with International and Australian Standards and with Vipac's NATA registration. The principal noise sources were identified on site by limiting the assessment to those sources with sound powers greater than 90 dBA and located primarily outside buildings.

- Construction of a detailed environmental noise model

  The model, developed within the SoundPlan software environment (Version 4.0), includes the effects of topography, propagation, shielding and reflections, and the plant physical and acoustic details with modelling algorithms in accordance with ISO 9613 and VDI 2714, widely accepted by environmental protection agencies. The CONCAWE algorithm is used to determine the effects due to varying meteorological conditions.

  Calm meteorological conditions were assumed (no wind and average temperature and humidity); such conditions are typical and are favourable for the propagation of noise. However, the 'worst case' weather conditions would be a north wind, high humidity, cloud cover and temperature inversion; such a situation is a rare occurrence at Olympic Dam.

- Noise models were generated for the three scenarios: existing baseline (85,000 t/a copper production), initial expansion (200,000 t/a copper production) and possible future expansion (350,000 t/a copper production).

- Sound power data were combined with coordinate geometry data obtained from plant layout drawings. Predictions were carried out for a 'worst case' operational scenario with all major noise sources operating. In the models for the existing operations, for the intermediate expansion and for the proposed full expansion there were 90, 140 and 180 noise sources respectively included. Approximately sixty plant buildings and structures were included in the model, either as barriers or reflecting walls or both.

- Prediction of environmental sound levels

  This was carried out for each scenario and covered critical areas within the operations plant, along the site fence line and also at the Roxby Downs township and the Olympic Dam Village. Both point sound levels and noise contour plots, showing the spatial noise distribution, and the ranking of sources to point sound levels were produced.

Figure M.1 shows the layout of sources and buildings for the 350,000 t/a copper production operating levels; the 85,000 t/a copper production and 200,000 t/a copper production layouts are included in Attachment 1 (Figures M.2 and M.3, respectively). The small circles in the plan view represent source locations. Control points at which verification measurements were carried out are shown as numbered. Measurements were made by Vipac at control points numbers 1 to 4 and WMC carried out measurements at points 5 and 6 (as part of a 1995 plant fence line noise survey). The conditions at the time of the measurements were still, clear and hot (35°C) with low humidity.

FIGURE M.1
PLAN VIEW OF NOISE SOURCES AND BUILDINGS FOR PROPOSED 350,000 t/a PLANT

M3.3 Results

M3.3.1 Existing operations (85,000 t/a copper)

The total A-weighted sound power level (PWL in dBA) of the existing plant principal noise sources was calculated from measurements to be ~140 dBA. In Attachment 1, Table M.1 presents measured sound power levels for major noise sources within the plant, and Table M.2 ranks the sources by their noise output for the present production and the proposed expansion to 200,000 t/a and 350,000 t/a copper production.

The major sources of acoustic power within the existing plant are:

- Shaft furnace (138 dBA)
- Autogenous mill No.2 and vibrating screen (134 dBA)
- Smelter anode furnaces (128 dBA)

- Calciner scrubber fan (126 dBA)
- Smelter flash furnace (125 dBA)
- Smelter electric furnace 124 dBA)
- Mullock stockpile crusher (123 dBA)
- Smelter casting wheel (122 dBA)
- Refinery cathode stripping machine (121 dBA).

Predictions were carried out for the current plant under calm meteorological conditions (see Section M3.2.2). Attachment 2 (Figure M.4) presents a contour map of predicted sound levels over the plant, showing how the sound propagates away from the various in-plant noise sources towards the plant boundary. All plant sources were assumed to be operating continuously at full power and hence the prediction represents a worst case scenario.

Predicted sound levels within the plant and along the southern fence line are shown in Table M.3 together with measured sound levels (by Vipac and by WMC): there is generally close agreement, thereby providing good confidence in the developed models. The plant was not fully operating for measurements at control points 5 and 6, but most noise sources were present during the other measurements (during which conditions were still and clear).

Table M.3 Comparison of measured and modelled noise levels at control points

Control point	Maximum sound pressure level (dBA)	
	Measured	Model 1: Existing
1	76	78
2	63	64
3	64	67
4	64	66
5 (plant fence line)	60	65
6 (plant fence line)	60	62
O.D. Village	–	32
R.D. Township	approx. 30	max. 20

This represents a good level of verification of the modelling process. The typical error inherent in the model results is approximately ±2 dBA. Ranking of sources relative to their contribution to the sound level at the four main control points within the plant is presented in Attachment 1 (Table M.2).

The prominent noise sources at control point 1 (40 m across the road from the smelter building) are the various furnaces of the smelter, the most dominant source being the shaft furnace (contributing 75 dBA). The noise generated by the smelter processes propagates well due to the openings in the west, south and east walls of the smelter building.

The dominant noise sources at control point 2 (corner of 1st Avenue and 2nd Street) are the cooling tower fans and sides. The cooling tower pumps generate reasonable sound power but are situated at ground level and are partially shielded by the cooling tower structure relative to the control point location.

Noise at control point 3 (corner of 1st Avenue and 9th Street, across the road from the ammonia tanks) is dominated by the No. 2 autogenous mill and the vibrating screen. The mullock crushers and the calcination scrubber fan also feature as significant sources.

The main sources of noise at control point 4 (corner of 5th Avenue and 9th Street) are the shaft furnace and the compressor station (exhaust fans on the western side). The shaft furnace has greater sound power than the other furnaces and, as it is located outside the eastern wall of the smelter building, the noise it generates propagates well to the east and south of the smelter area.

As shown in Table M.3, noise levels along the operations site fence line are generally less than 60 dBA (from the WMC 1995 fence line survey) and up to a maximum of 65 dBA (from the model results with full plant operation) along part of the southern fence line (see Figure M.4 in Attachment 2). The plant noise level at the Olympic Dam Village, adjacent to the southern boundary of the Special Mining Lease, is close to the background level.

The predicted township noise levels are of the same order as those estimated in the 1983 EIS noise survey (Vipac 1982). Noise levels at Roxby Downs township due to baseline plant operation are expected to be less than 20 dBA which is in accordance with observations; i.e. the noise from the mine site and processing operations is not detectable within the township when background noise levels (L_{95} dBA) are of the order of ~30 dBA. The plant noise level at the Olympic Dam Village is close to the background level.

M3.3.2 Initial (200,000 t/a copper) and possible future expansion (350,000 t/a copper)

The initial expansion (200,000 t/a copper production) incorporates the addition of a range of new plant structures, operating machinery and noise sources. The new major sources of noise are the addition of a larger autogenous mill (No. 3) and those associated with a new smelter (No. 2), acid plant (No. 2), oxygen plants (No. 2), cooling towers and extensions to the refinery complex and compressor station.

Other additional minor sources are associated with the new copper/uranium (Cu/U) solvent extraction area, feed preparation and flotation areas, and CCD/clarification and tails areas. The existing smelter, acid plant and oxygen plant are assumed to stop operating once the new plants come on line in the expansion phase.

The possible future expansion to 350,000 t/a copper production includes new noise sources associated with a matte smelter (No. 3), acid plant (No. 3), refinery complex (No. 2), electrowinning complex, extensions to autogenous mills and lower level sources in new Cu/U solvent extraction, feed preparation and flotation areas, and CCD clarification and tails areas. The bulk of the 200,000 t/a expansion sources are assumed to be operating along with the new full expansion sources. For the projection, it was assumed that the new smelter buildings would be more enclosed than the existing smelter plant and would have slightly quieter and more efficient furnaces.

The noise model was modified to include the new sources (based on existing and reference noise data), extrapolations to some existing sources and extensions to or additional structures and buildings. As in the existing operations, the model was run for the two expansion scenarios to generate noise contour plots and single point noise levels and source rankings at each of the control points.

The noise contour plots for the expansion scenarios are shown in Figures M.5 and M.6 in Attachment 2. A comparison of model predicted noise levels at the control points is provided in Table M.4.

The noise level at control point 1 drops significantly (by 7 dBA) in the expansion phases as the existing smelter ceases operation. The noise level at control point 2 increases by up to 7 dBA due to its proximity to the new smelters. The noise level at control point 3 increases by up to 10 dBA due to the addition of the autogenous mill No. 3 and the vibrating screen. The noise level at control point 4 increases due to the addition of autogenous mill No. 3 and the CCD and tails area established nearby; the noise level drops slightly in the full expansion due to shielding by new structures (e.g. reagents storage).

Table M.4 Comparison of predicted noise levels at site control points

Control point	Maximum sound pressure level (dBA)		
	Model 1: Existing	Model 2: 200,000 t/a copper production	Model 3: 350,000 t/a copper production
1	78	71	71
2	64	69	71
3	67	76	77
4	66	72	71
5 (plant fence line)	65	63	63
6 (plant fence line)	62	65	67
O.D. Village	32	34	34
R.D. Township	19	20	20

The noise level at control point 5 on the southern plant fence line actually drops (by 2 dBA) as a result of the existing smelter closing down and due to shielding by new buildings (offices, laboratories etc.) to the north of the control point. The noise level at control point 6 increases by up to 5 dBA due to the addition of closer noise sources in the south-east sector over time.

Ranking of sources relative to their contribution to the total sound level at the four main control points within the plant for the expansion phases is presented in Attachment 1 (Table M.2).

The prominent noise sources at control point 1, once the existing smelter is not operating, would be the compressor station, the new oxygen plant and the cooling towers. The dominant noise sources at control point 2 would now be the new smelters and cooling towers. Control point 3 would be dominated by the new autogenous mill No. 3 and vibrating screen. Control point 4 sources include the autogenous mills and the pumps/drives in the new nearby CCD and tails areas.

Noise levels along the operations site fence line remain generally less than 60–62 dBA (see Figure M.4 in Attachment 2) and reach up to a maximum of 67 dBA (at control point 6) with full expanded operation. The predicted township noise levels are still expected to be about 20 dBA, and the level at Olympic Dam Village (near the boundary of the Special Mining Lease) is expected to increase by only 2 dBA and remain close to the existing background level.

The 'worst case' weather conditions (see Section M3.2.2) could cause a 3–4 dBA increase in noise levels at the control points and a 4–5 dBA increase at the village/township. Such differences are not considered significant and would occur on rare occasions.

M3.4 Assessment

The site fence line sound levels reach a maximum of 67 dBA (with full plant operations for proposed 350,000 t/a copper production expansion) along part of the southern fence line and are generally lower than 60 dBA elsewhere along the fence line.

At Olympic Dam Village, which is adjacent to the boundary of the Special Mining Lease, the noise level is predicted to be 34 dBA for the initial and future expansion scenarios. As these levels are below the criterion limit of 70 dBA for an industrial zone, noise levels from the WMC plant expansion therefore comply with the regulations of the *Environment Protection Act* (refer Section M4.1).

Sound levels in the township will not increase significantly due to the WMC plant expansion and in any event will be some 5–10 dBA below the township minimum background sound levels. The levels at the Olympic Dam Village will remain within 5 dBA of the background level. The expected sound level of about 20 dBA is well below the criterion limit of 45 dBA at night for residential areas and even less than the 40 dBA limit for rural areas; hence, the plant expansion will comply with the *Environment Protection Act.*

Relative to the AS 1055 standard (Standards Australia 1989), the noise level exceeded for 10% of the time (L_{10}) at both the plant fence line and in the village/township due to expanded plant operations is not expected to exceed the existing background level by more than 5 dBA.

Local traffic levels are likely to increase gradually over the expansion period. This will be a result of the possible increase in heavy vehicle transportation of concentrate between Whyalla and Olympic Dam, in addition to an increase in local traffic levels due to the projected rise in population (plant personnel and township residents). Average noise levels generated from these marginal traffic increases (up to a maximum of a 3 dBA increase in the L_{10} (18 hour) level) over substantial periods of time are not expected to be significant or annoying.

Given that there is no significant environmental noise impact caused by either the initial or possible future expansion, mitigation measures are not required and do not need to be recommended.

M4 OCCUPATIONAL NOISE ASSESSMENT

M4.1 Criteria

The Occupational Health, Safety and Welfare (OHSW) Regulations (1995) provide standards in the form of noise exposure limits for employees within workplaces. Compliance is stated as the required duty of employers in addition to the responsibility of employees.

The upper limit for the 8-hour equivalent continuous A-weighted sound pressure level, L_{eq}(8 hour), is currently 90 dBA. However, a stricter standard of 85 dBA is planned for introduction in 1997.

Many employees at the operations site work twelve hour shifts which will imply lower effective criterion levels. The effective limits for twelve hour shifts respectively become 87.2 dBA (from 90 dBA) and 83.2 dBA (from 85 dBA).

In addition, WMC has a working policy of 85 dBA noise level limit for the Olympic Dam operations site. A design criterion of 80 dBA has been set for the Expansion Project. Where this level cannot be met by engineering design, hearing protection is required.

M4.2 Methodology

M4.2.1 Overview

Measured occupational noise levels from existing surveys of occupied spaces are summarised and reviewed for each sector of the operations plant and assessed against OHSW regulation criteria.

Using the existing plant operations as a baseline, future expansion phases are investigated and any predicted impacts from modelling are identified and assessed relative to the regulations. Mitigation measures are investigated and recommended to ameliorate any significant occupational impacts.

Mitigation strategies are developed for operational, engineering and administrative controls to limit the effects to comply with regulations and avoid plant restrictions. This may include updating of noise and related specifications.

M4.2.2 Modelling

The noise levels generated by the two phases of the expansion are predicted using the SoundPlan noise model, described in Section M3.2. The ranking of major sources at control points, determined for each phase, has been presented in Section M3 and Attachment 1.

Verification of the methodology for the existing operating level (85,000 t/a copper production) has been provided by comparison of measured and predicted noise levels at control points (see Section M3.3).

Expected occupational noise levels over areas within and around major plant operations are determined with definitions and extents of key risk areas.

M4.3 Results

The noise measurement data for specific in-plant areas are summarised in Attachment 3, providing a range of noise levels experienced in the various areas along with maximum levels in key areas.

In addition, actual noise levels experienced by a range of operators on site have been recorded by WMC in an Occupational Noise Survey, 1995; however, the measurements did not take into account octave band spectral information.

Sound levels in the vicinity of major plant items generally exceed the recommended twelve-hour average of 83 dBA, and range from 84 to 107 dBA. Employees in these environments are thus required to use a form of hearing protection to reduce the 'in-ear' sound pressure level to less than 83 dBA. In most cases, ordinary earplugs are satisfactory, reducing the sound level incident upon the employees' ears by 20 dBA.

Table M.5 highlights the key site areas in regard to occupational noise levels.

Table M.5 Measured noise levels experienced by operators in key site areas

Location/activity	Measured noise level (dBA)
Concentrator—mullock stockpile truck operator	107
Met. labs—sample preparation operator	101
Refinery—stripping machine operator	101
Slag concentrator—truck operator	107
Smelter—casting wheel operator	101
Smelter—shaft furnace operator	103

The modelling shows that the affected areas of high noise level increase during the expansion phases (refer Section M.4 and Figures M.5 and M.6 in Attachment 2). Table M.6 provides the approximate affected plant area, greater than the twelve hour criterion of 83 dBA, for each of the expansion phases compared to the existing operations.

Table M.6 Change in high noise affected plant areas

Operational scenario	Affected area > 83 dBA* (m^2)
Existing baseline	50,000
Intermediate expansion	120,000
Full expansion	140,000

* *Using existing operations as a baseline.*

The approximate area affected by high noise levels increases substantially over time throughout the expansion process, using the existing operations as a baseline.

Noise sources at mine shafts (Whenan, Robinson and proposed No. 3) are associated with equipment such as the surface drill rig, winder facility, dump hoppers and bins, bit sharpening machines, etc. Noise levels generated are generally not significant; however, noise levels next to a drill rig reach 103 dBA and those in the winder facility reach 95 dBA next to the generators.

Underground noise levels are dominated by mobile equipment such as rockbreakers, drill jumbos, jumbo tamrocks, charge-up vehicles, front end loaders and graders. In addition, other sources are associated with equipment such as loading and crushing stations, grizzlies, hoisting facilities, pumping stations, auxiliary fans, ventilation regulators and rail loading chutes.

Some of the underground mobile equipment (rockbreakers, drilling rigs, etc.) can have sound power levels of the order of 120–130 dBA, which will generate maximum sound pressure levels over 100 dBA within 5 m distance.

There is a WMC requirement for all employees working underground to wear quality ear muffs. Such hearing protection provides 25–30 dBA noise attenuation which ensures that employees are exposed to less than 85 dBA equivalent noise level over an eight-hour period.

M4.4 Assessment

The in-plant occupational noise and the number of employees and contractors at risk are both likely to increase during the expansion phase. To minimise and control the risk of hearing damage, various control strategies are appropriate. These include:

- Equipment purchase—incorporation of appropriate noise specifications in equipment purchase contracts, to take into account the installation environment and the need to comply with OHSW regulations. Specification of a free-field limiting sound level of 85 dBA is not adequate as several sources will often combine to exceed the free-field level.
- Noise control—use where practical of engineering noise control for major sources, such as:
  - noise-reduced, higher efficiency burners and gas jets for smelter furnaces
  - vibrating screens and autogenous mill
  - calciner scrubber fan
  - refinery cathode stripping machine.
- Hearing protection—mandatory requirement for hearing protection along with the placement of clear signage at the entrances to and within plant areas where noise levels are excessive. Regular checks on personnel and greater control of hearing protection application are necessary. Basic ear plugs should be worn in any area and quality ear muffs in critical areas greater than 95 dBA. In the selection of hearing protection, the actual noise spectra and the variation in attenuation of actual hearing protection devices used over a period of time need to be considered in the selection of hearing protection.
- Monitoring—use of noise dosimetry assessment in operator monitoring and regular hearing tests. The variation in operator tasks or activities in each site area should be properly determined and the resultant noise dose quantified with spectral data over longer periods of time. In addition, the variation in attenuation of actual hearing protection devices used over a period of time should be determined.
- Training—implementation of appropriate training programmes of workers and supervisors in accordance with the OHSW regulations.

M5 CONCLUSIONS AND RECOMMENDATIONS

Environmental noise is not a significant issue either in the Roxby Downs township or along and just beyond the Special Mining Lease boundary. No mitigation measures are thus required in this area.

Occupational noise is potentially a significant health risk and could become more so during the plant expansion process. Hearing protection is required in key areas within the plant. These areas need to have appropriate signage, and employees and contractors need to be made aware of noise issues by appropriate training. Monitoring is necessary to assess operator exposure.

Control of noise levels by use of appropriate noise specifications in equipment purchase contracts, and use of engineering noise control, should be adopted.

ATTACHMENT 1—ENVIRONMENTAL NOISE ASSESSMENT: INPUT AND OUTPUT DATA

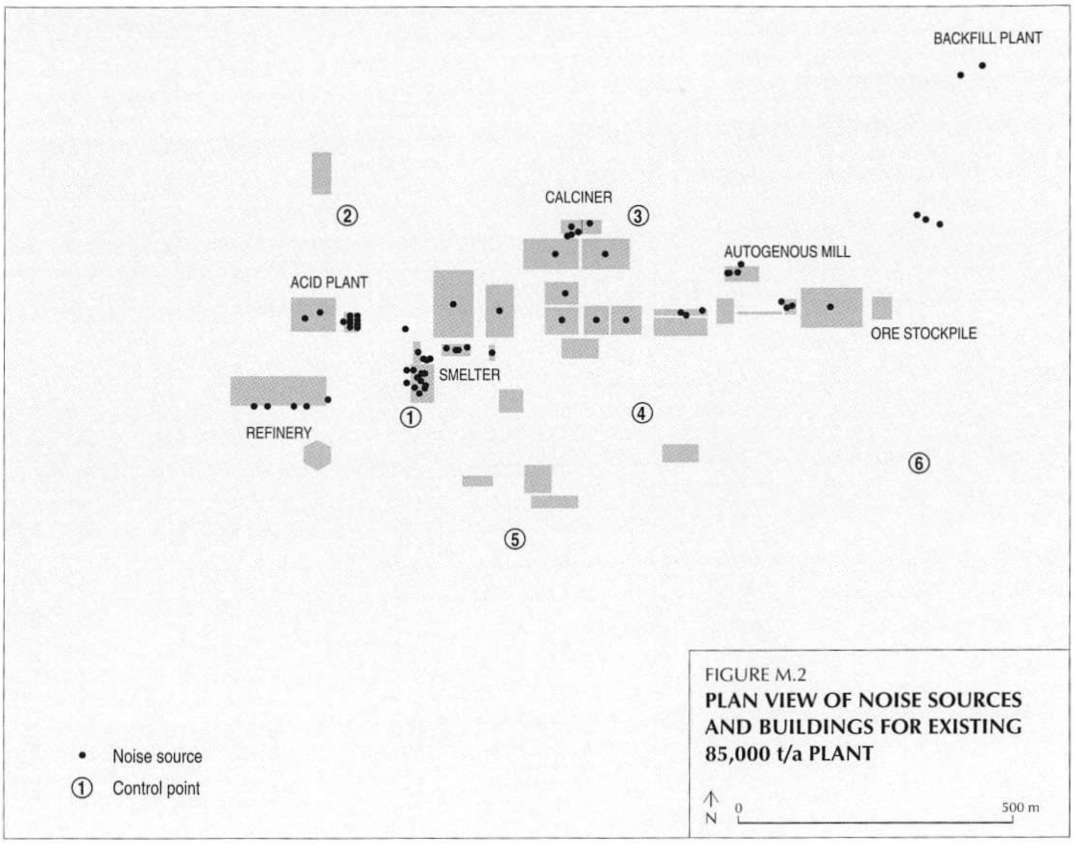


FIGURE M.2
PLAN VIEW OF NOISE SOURCES AND BUILDINGS FOR EXISTING 85,000 t/a PLANT

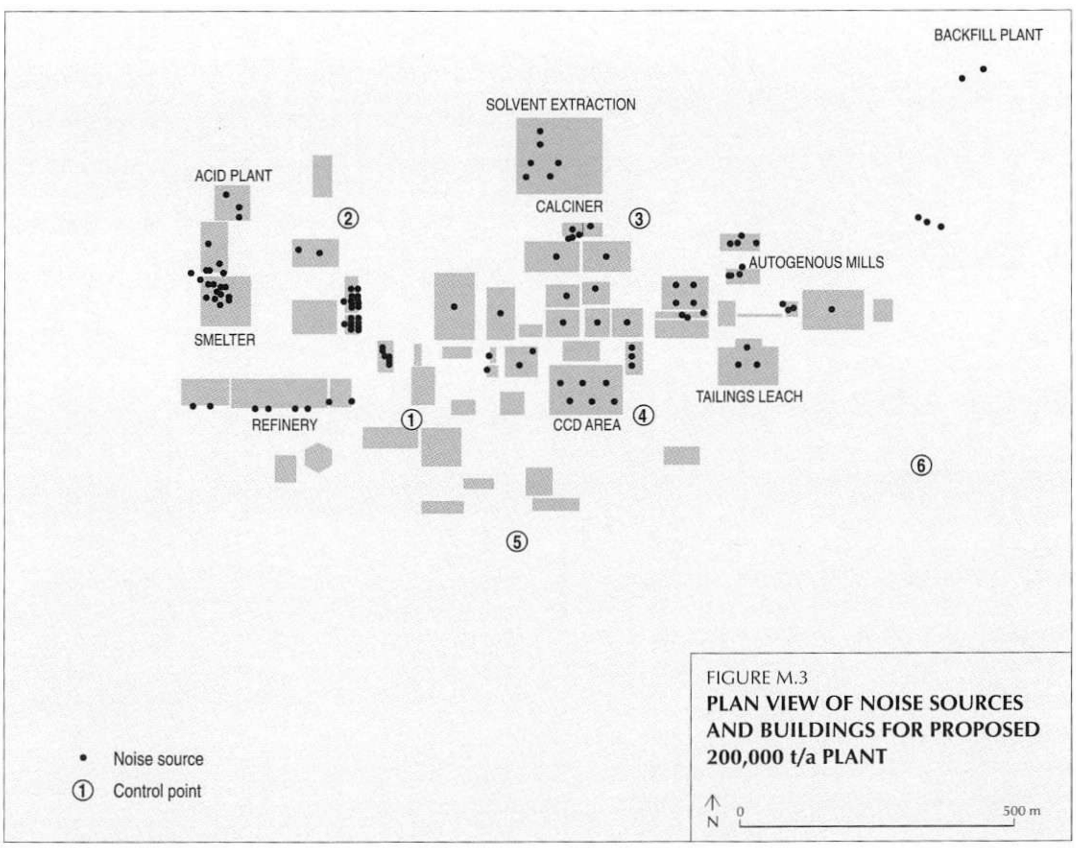


FIGURE M.3
PLAN VIEW OF NOISE SOURCES AND BUILDINGS FOR PROPOSED 200,000 t/a PLANT

Table M.1 Sound power data

Record	Item/source	A-weighted octave band power spectrum (dBA)										
		32	63	125	250	500	1k	2k	4k	8k	16k	Total
1	CAL TONE	41	41	41	117	59	78	73	54	41	41	117
2	AF 1	75	89	101	110	110	109	106	101	94	80	115
3	EF	79	89	101	104	110	118	112	109	104	92	120
4	FAN 1M	62	74	86	104	102	103	100	92	84	71	108
5	AF 2 1M	66	78	94	109	107	102	97	92	86	79	112
6	FF 2	75	87	102	111	112	109	107	105	103	96	117
7	FF 4	57	67	81	91	91	91	88	86	78	69	97
8	FF 5 F	54	66	79	89	89	89	85	80	74	60	94
9	FF 5 G	53	67	80	89	89	90	92	87	80	74	97
10	FF 3 FAN	74	81	84	105	105	106	103	95	84	74	111
11	WHB 2	65	74	85	90	95	103	100	97	90	82	106
12	B STACK	88	93	102	105	108	113	119	121	110	96	124
13	SM W1	78	89	98	106	107	106	104	99	90	78	112
14	SM W2	75	87	97	105	108	107	105	101	88	74	113
15	SM S3	72	88	97	105	106	106	108	102	89	74	113
16	SM CT	70	91	102	101	104	103	102	97	92	82	110
17	BH FAN	64	84	90	99	103	102	100	94	90	78	108
18	SM S4	73	83	96	104	106	105	102	98	92	82	111
19	SM PUMPS	63	79	91	100	98	104	101	95	85	71	107
20	SM MOTOR	62	80	104	93	100	100	95	89	77	63	107
21	OP PIPES	53	65	84	83	90	96	92	94	88	76	100
22	OP VENT	58	71	83	87	95	99	108	112	106	97	115
23	OP OVERALL	54	67	83	81	86	89	92	89	86	80	96
24	COMP ST (EXT)	75	91	108	111	113	113	118	118	113	103	123
25	COMP ST (INT)	49	66	80	85	94	95	100	101	94	84	105
26	REF 1	70	84	98	108	114	116	117	114	102	85	122
27	REF 2	58	75	99	101	99	100	97	92	85	74	107
28	REF 3	61	77	91	98	101	98	101	101	89	73	107
29	REF CSM	72	79	91	100	107	113	121	129	129	123	133
30	REF CSM 2	66	83	95	105	112	114	114	113	106	93	120
31	BP MIXER	79	89	98	111	120	122	121	117	103	91	127
32	MS 1	72	93	101	110	116	118	115	110	101	87	122
33	MS 2	73	93	104	111	117	121	122	119	110	96	126
34	MS 3	83	104	114	121	123	125	125	120	113	101	131
35	PC FAN	56	76	94	103	105	106	105	101	98	88	112
36	PC	67	80	91	105	108	107	104	102	95	84	113
37	PC 2	58	72	83	93	99	99	99	100	99	93	107
38	PC STACK	76	91	100	109	113	113	108	105	104	95	118
39	AM 2 L1	84	94	104	108	111	122	114	107	104	96	124
40	AM 2 L2 - F	85	96	107	112	116	132	124	117	116	109	133
41	AM 2 L2	99	109	118	124	129	130	123	117	113	102	134
42	AM 2 FAN	65	71	84	95	97	98	96	92	85	71	103
43	FA REGRIND	75	86	99	103	104	107	102	97	88	77	111
44	FA FANS	58	73	80	94	99	99	99	100	95	82	106
45	REF 4	66	78	89	98	105	108	106	105	98	83	113
46	CT SIDE	92	101	110	113	109	106	109	100	94	84	117
47	CT PUMPS	64	74	77	88	91	101	97	88	79	69	103
48	CT FANS	88	106	108	114	115	113	107	103	95	84	120
49	SF 1	77	93	114	122	130	132	131	133	130	122	138
50	AP SO2	66	82	92	94	97	103	107	109	96	77	112
51	CAST	77	96	112	116	115	115	123	122	117	106	127
52	SM S3 CW	74	88	103	110	113	110	110	108	99	81	118
53	SM S4 SF	77	89	105	113	118	114	111	109	101	87	121
54	SF GD	80	92	105	115	120	118	115	114	109	95	124

Table M.2 Noise sources: ranked for each scenario at site control points 1, 2, 3 and 4

Existing plant		200,000 t/a copper		350,000 t/a copper	
Noise source	dBA	Noise source	dBA	Noise source	dBA
CONTROL POINT NO. 1 (40 m SOUTH OF SMELTER BUILDING)					
Shaft furnace	75	Compressor st.	67	Compressor st.	67
Anode furnaces	69	Oxygen pl. No.2	63	Oxygen pl. No.2	63
Electric furnace	67	C/T 1 and 2 fans	59	C/T 1 and 2 fans	59
Flash furnace	66	Refinery pipes	57	Refinery pipes	57
Casting wheel	65	Refinery r. fans	55	Refinery r. fans	55
Baghouse and C/T	63	C/T 1 and 2 sides	54	C/T 1 and 2 sides	54
CONTROL POINT NO. 2 (CORNER OF 1ST AVENUE AND 2ND STREET)					
C/T fans	58	Smelter No.2	66	Smelter No.3	68
C/T sides	56	C/T 1&2 fans	64	Smelter No.2	66
Shaft furnace	55	C/T 1&2 sides	63	C/T 1&2 fans	64
Compressor st.	52	Feed Pr.2 pumps	57	C/T 1&2 sides	63
Anode furnaces	50	C/T 1&2 pumps	56	Feed pr.3 pumps	59
C/T pumps	48	Compressor st.	54	Feed pr.2 pumps	57
CONTROL POINT NO. 3 (CORNER OF 1ST AVENUE AND 9TH STREET, ACROSS ROAD FROM AMMONIA TANKS)					
Autog.M.2 vibr.	64	Autog.M.3 vibr.	72	Autog.M.3 vibr.	72
Autog.M.2 mill	62	Autog.M.3 mill	71	Autog.M.3 mill	71
Mullock crushers	58	Autog.M.2 vibr.	64	Autog. sec. mills	66
Calcin. scr. fan	56	Autog.M.2 mill	62	Autog.M.2 vibr.	64
Pebble crusher	53	Mullock crusher	59	Autog.M.2 vill	62
Precip. pumps	52	Calcin. scr. fan	56	Mullock crusher	60
CONTROL POINT NO. 4 (CORNER OF 5TH AVENUE AND 9TH STREET)					
Shaft furnace	64	Autog. mill No.2	69	Autog. mill No.2	68
Compressor st.	57	Autog. mill No.3	65	Autog. mill No.3	64
Autog. mill No. 2	55	CCD 2 pumps	63	CCD 2 pumps	63
Pebble crusher	52	Tails leach No.2	59	Tails leach No.2	59
Anode furnaces	50	Tails thick. No.2	56	Tails thick. No.2	56
Other furnaces	49	Compressor st.	54	CCD 3 pumps	55

ATTACHMENT 2—NOISE CONTOUR PLOTS

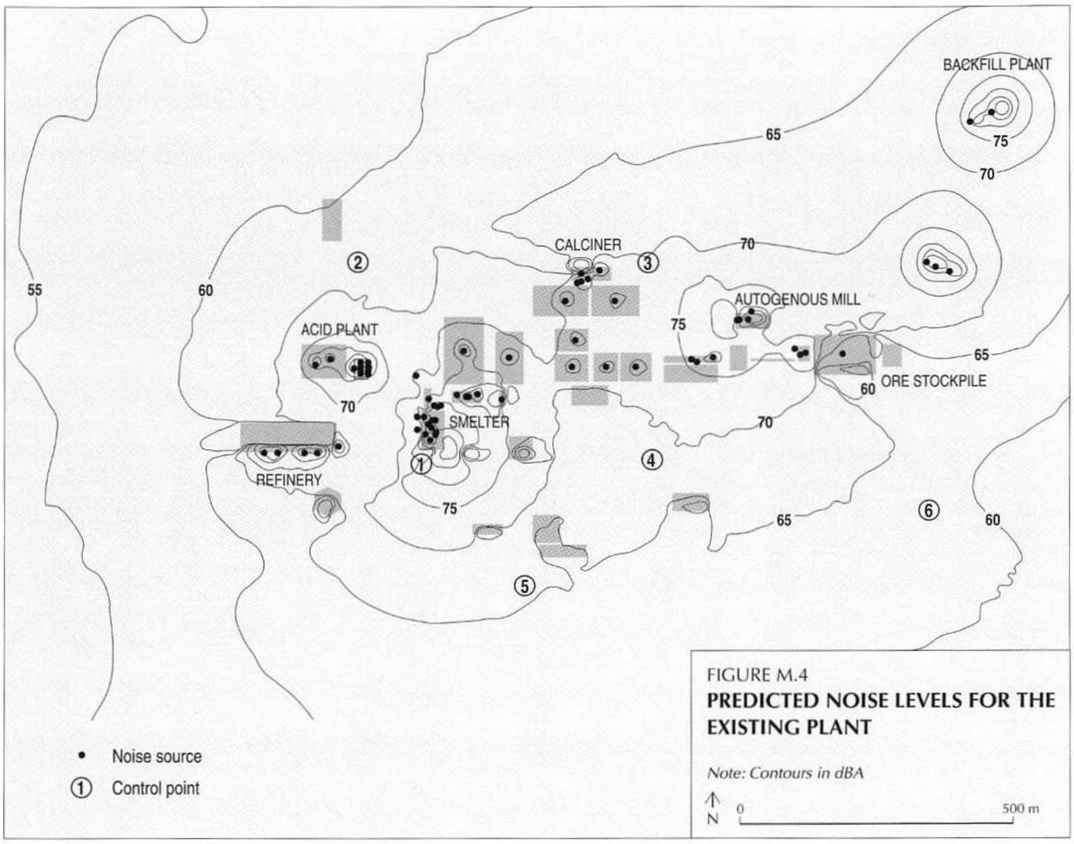


FIGURE M.4
PREDICTED NOISE LEVELS FOR THE EXISTING PLANT

Note: Contours in dBA

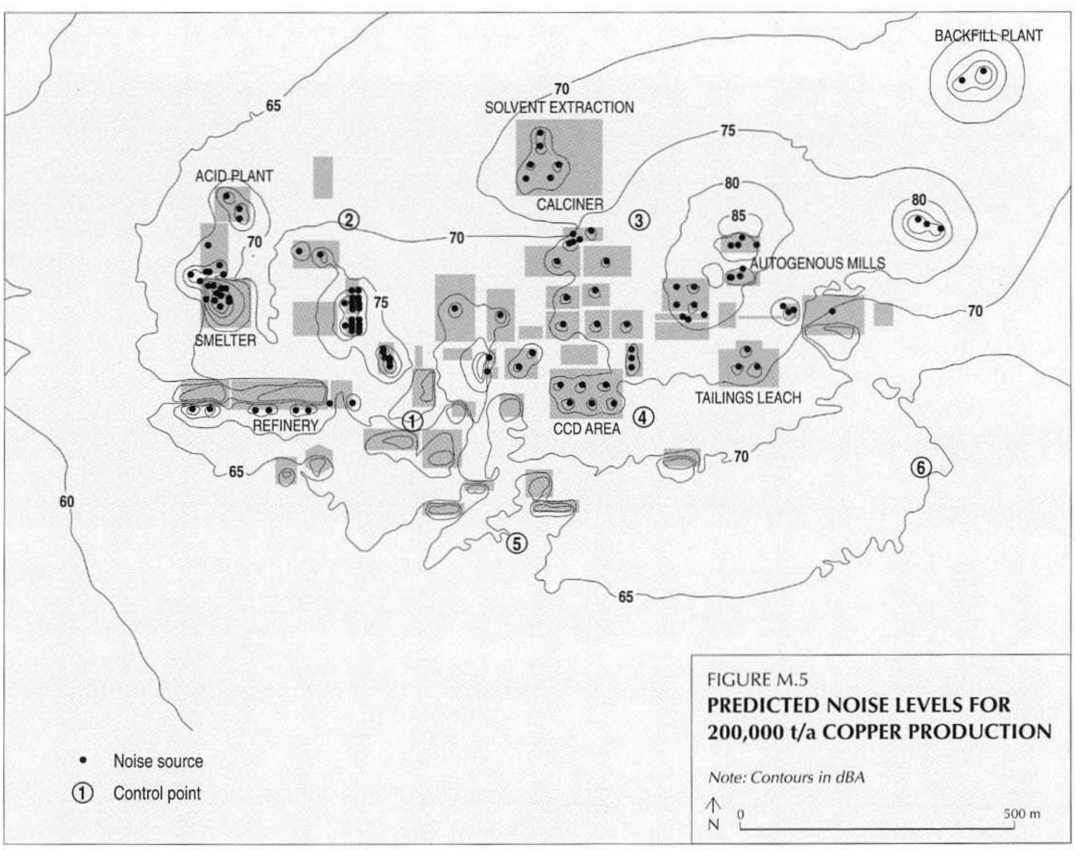


FIGURE M.5
PREDICTED NOISE LEVELS FOR 200,000 t/a COPPER PRODUCTION

Note: Contours in dBA

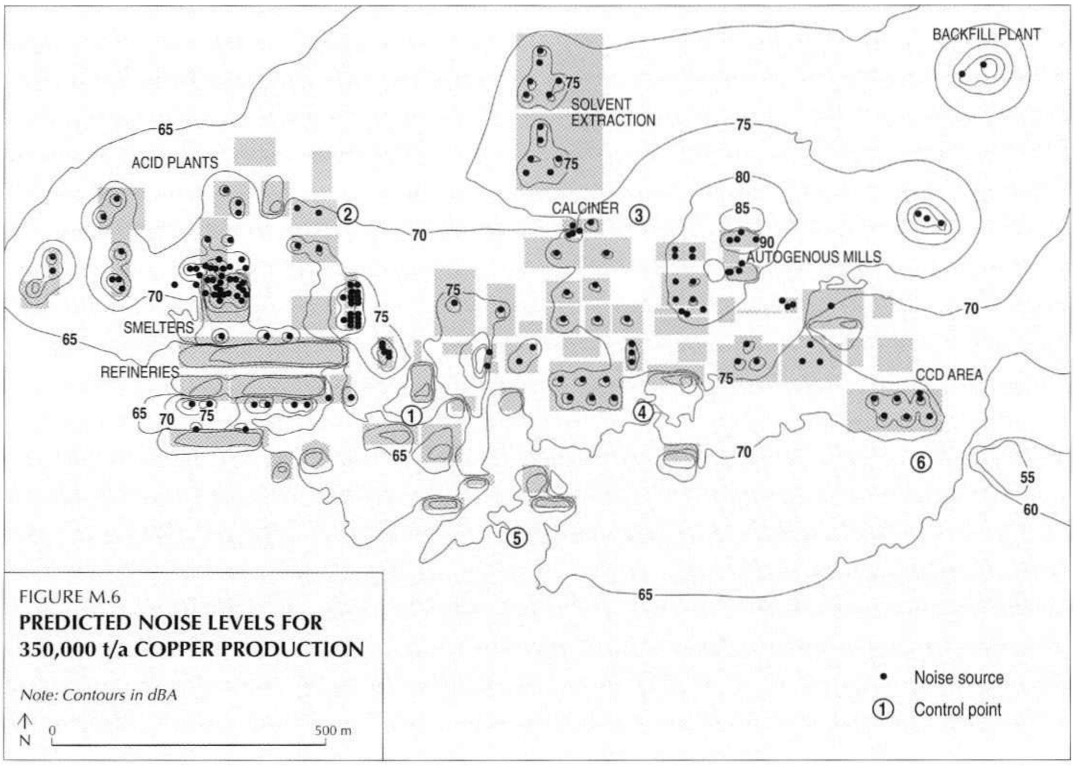


FIGURE M.6
PREDICTED NOISE LEVELS FOR 350,000 t/a COPPER PRODUCTION

Note: Contours in dBA

N 0 500 m

ATTACHMENT 3—OCCUPATIONAL NOISE ASSESSMENT: MEASUREMENT DATA

Smelter

Oxygen plant (71–100 dBA)

• During gas release	85 dBA
• At back of storage tanks during gas release	100 dBA
• Under large pipes and valves	87 dBA
• Along eastern fence	88 dBA

Compressor station (80–97 dBA)

• Compressors	97 dBA
• Exhaust fans	92 dBA

Tapping level (86–98 dBA) (Both anode furnaces heating; shaft furnace not operating)

• All locations	> 85 dBA
• Anode furnaces	97 dBA
• Anode furnaces during oxy-injection	105 dBA
• Adjacent slag tapping holes	93 dBA

Control room level (87–96 dBA)

• All locations	> 85 dBA
• Near uptake shaft	96 dBA

Concentrate burner level (89–96 dBA)

• All locations	> 85 dBA
• Near flash furnace	96 dBA

Feed burner level (88–92 dBA)

• All locations	> 85 dBA

Casting wheel (74–92 dBA)

• All areas outside control room	>85 dBA

Shaft furnace (72–101 dBA)

• All locations (except 4th floor)	> 85 dBA
• Ground level—casting wheel	93 dBA
• First level—tapping hole	101 dBA
• Second level (general)	89 dBA
• Third level—charging door	93 dBA

Electrostatic precipitator and waste heat boiler (72–84 dBA)

• Near waste heat boiler	84 dBA

ATTACHMENT 3—OCCUPATIONAL NOISE ASSESSMENT: MEASUREMENT DATA (continued)

Acid plant (63–83 dBA)

• Near storage tanks	83 dBA
• Inside SO_2 blower room	95 dBA

Concentrator

Tripper (72–88 dBA)

• Near drop point	88 dBA
• Conveyor belt motor	84 dBA

Reclaim tunnel (81–93 dBA)

• Along conveyor belt	90 dBA
• Near falling rocks	93 dBA

Pebble crusher (83–99 dBA)

• Gnd level—conveyor noise	87 dBA
• 1st level—crusher operation	99 dBA
• 2nd level—crusher operation	96 dBA
• 3rd level—rocks onto conveyor	97 dBA
• 5th level—near feeding point	96 dBA

Autogenous Mill No. 2 (80–105 dBA)

• Ground level (general)	90 dBA
• 1st level—vibrating screen	105 dBA
• 2nd level—vibrating screen	105 dBA
• 3rd level—feeding area	83 dBA

Flotation area (75–89 dBA)

• Tailings thickener	89 dBA
• Tails leach feed surge tank	88 dBA
• Motors in flotation area	86 dBA
• Noise from re-grinding	86 dBA

Reagents storage area (57–77 dBA)

- No critical noise levels

Backfill plant (74–96 dBA)

• Near motor at bottom of storage tanks	96 dBA
• Along walkway next to control room	87 dBA
• Below cement mixers	85 dBA
• Truck loading	85 dBA

ATTACHMENT 3—OCCUPATIONAL NOISE ASSESSMENT: MEASUREMENT DATA (continued)

Mullock crusher (79–96 dBA)

• Next to crusher	96 dBA
• Loading of truck	94 dBA
• Conveyor noise	86 dBA

Hydrometallurgical Plant

Tailings leach, concentrate leach, clarification, CCD, copper and uranium solvent extraction, and yellowcake areas (65–85 dBA)

• Near motors and pumps	Up to 92 dBA
• Near high pressure valves	82 dBA

Tailings deslimes (68–93 dBA)

• Near motors and pumps	Up to 93dBA

Calciner building (67–106 dBA)

• Venturi scrubber extraction fan	106 dBA
• Second level exhaust fan	90 dBA

Feed preparation (70–96 dBA)

• High frequency noise under conveyor	96 dBA
• Above tank adjacent large motor	91 dBA

Mine Surface

Shaft 2 (67–78 dBA)

- No critical noise levels

Bit sharpening shed (94–96 dBA)

• Adjacent bit sharpening machines	96 dBA

Winder room (78–94 dBA)

• Adjacent generators	94 dBA
• Adjacent winders	86 dBA

Surface drill rig (94–103 dBA)

• Personnel next to drill rig	103 dBA
• Air blower	102 dBA

Workshop (63–75 dBA)

- No critical noise levels

ATTACHMENT 3—OCCUPATIONAL NOISE ASSESSMENT: MEASUREMENT DATA (continued)

Refinery

Tank house (74–96 dBA)

• Operation of light machinery	86 dBA
• Cathode stripping machine	96 dBA

Gold room (79–87 dBA)

• Near roaster	87 dBA
• Near storage tanks	87 dBA

Technical Services (66–94 dBA)

Incorporates sample preparation room, analytical laboratory and metallurgical workshop

• Angle grinding (metallurgical workshop)	92 dBA
• Drilling (metallurgical workshop)	94 dBA
• Air hose/lathe operation	97 dBA

APPENDIX N

IONISING RADIATION —AN INTRODUCTION

APPENDIX N

IONISING RADIATION —AN INTRODUCTION

N1 URANIUM

Uranium is a radioactive element found in nature. There are three types (isotopes) of uranium found naturally. These are uranium-238 (^{238}U), uranium-235 (^{235}U) and uranium-234 (^{234}U). Natural uranium consists of approximately 99.3% ^{238}U and 0.7% ^{235}U. Uranium-234 is a decay product of ^{238}U. Uranium-235 is able to undergo nuclear fission, which means that it can be split into smaller fragments, thereby releasing energy. This property is exploited in nuclear power reactors where ^{235}U is used as a fuel in electricity production.

Since uranium is radioactive, it is axiomatic that people who work at uranium mines and processing plants will be exposed to radiation, over and above the radiation to which they would be exposed if they did not work at a mine or processing plant. The ways in which a radiation dose can be acquired in uranium mining, and the types of radiation associated with uranium, have been studied for many years.

Indeed, the problems associated with the health of silver miners in mines where uranium also occurred were studied as early as the fifteenth century, with 'Bergsucht' ('mountain sickness'), or lung diseases, for example, being reported by Paracelsus (1493–1541). The frequencies of these diseases increased in the seventeenth and eighteenth centuries and came to be called 'Schneeberger Lungenkrankheit', after the Schneeberg district between Saxony and Bohemia in which silver was mined by underground methods.

There remains a great deal of debate as to the actual causes of the diseases associated with underground uranium mining; nevertheless, the scientific literature is abundant, and it is upon this literature that modern radiation safety for miners is based.

Uranium-238 itself is only mildly radioactive, having a half-life of 4,500,000,000 years. In other words, it takes four and a half billion years for half the uranium atoms in a sample to decay. Uranium-238 decays by the emission of an alpha particle to thorium-234 (^{234}Th), which has a half-life of 24.1 days and decays by the emission of beta and gamma radiation to form protactinium-234 (^{234}Pa), which has a half-life of 1.17 minutes.

In all, the uranium decay series consists of fourteen stages (Figure 2.17). While each individual element in the series has its own unique half-life, no decay product can decay before it is formed by the decay of its 'parent'. Thus, in its undisturbed state, the uranium decay series decays at the same rate as the ^{238}U itself. This state is called 'secular equilibrium', and is an important concept in radiation dose assessments in mines.

All the elements in the ^{238}U decay series are solids with the exception of the gas radon, and under normal circumstances do not move from their site of production. In the metallurgical process that extracts uranium from the ore in which it is found, the decay series is disrupted, and elements are diverted into a number of different process streams. This also has important implications for radiation protection and dose assessment.

Radium-226 (^{226}Ra) is a member of the uranium decay series. When it decays, it decays to a radioactive gas, radon (^{222}Rn). Being a gas, radon is able to move from its site of production inside the crystal lattice of the host rock, and has the potential to become airborne. Radon-222 decays with a half-life of 3.82 days and with the emission of an alpha particle to a solid product, polonium-218 (^{218}Po), which has a half-life of 3.05 minutes. Polonium-218 also decays by alpha emission, as do others of the radon decay products. Lead-206 (^{206}Pb) is the stable end-product of the series.

There are therefore two main ways in which a radiation dose can be acquired at uranium mines and processing facilities:

- direct irradiation by gamma and beta radiation from radioactive materials outside the body;
- internal irradiation by alpha particles emitted by radioactive materials taken into the body, either in the form of dust, or in the form of radon and radon decay products.

Radiation protection in uranium mining is therefore a matter of reducing the doses associated with these pathways. The means of reduction are explored in Section N10.

N2 RADIOACTIVITY

All matter is made up of atoms. Atoms themselves are made up of an arrangement of protons, neutrons and electrons. Radioactivity comes about because some elements (and isotopes of some elements) are unstable. The arrangement of protons, neutrons and electrons in radioactive elements is such that the atoms have an excess of energy. Anything in nature that has an excess of energy is unstable and will break down by giving up the excess energy until the atoms become stable. This is the law of entropy.

The way in which unstable atoms give up their excess energy is called radiation. The radioactivity associated with each radioactive element can be characterised by two parameters: the rate at which decay occurs and the types of radiation given off during decay.

The rate at which atoms of a radioactive element decay is described by the number of disintegrations occurring in a given time period, usually a second. The time taken for half the atoms of a radioactive element to decay is described by the 'half-life' of the element. Figure N.1 is a diagram of this phenomenon.

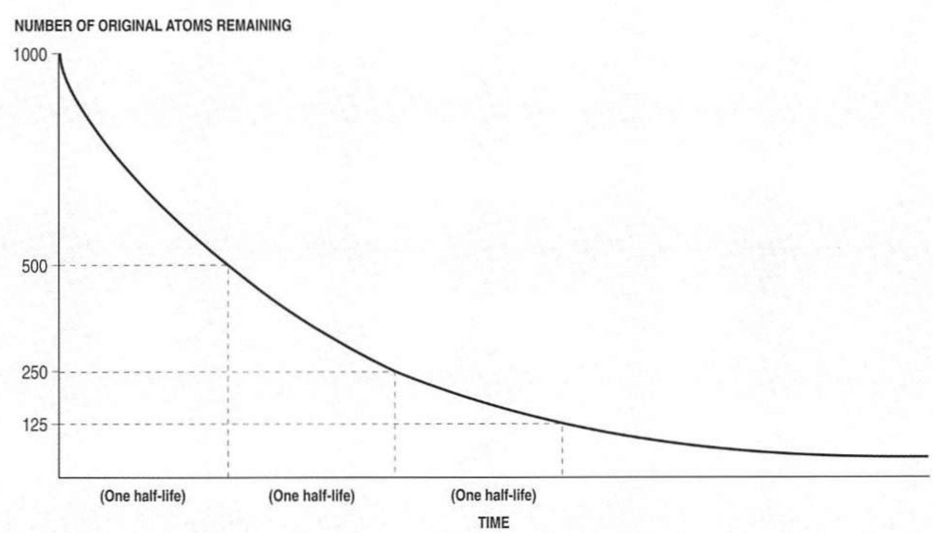


FIGURE N.1
DIAGRAMMATIC REPRESENTATION OF RADIOACTIVE DECAY IN HALF-LIVES

N3 RADIATION

There are two types of radiation: ionising radiation and non-ionising radiation. Ionising radiation includes X-rays and the radiation that comes from radioactive elements. Non-ionising radiation includes light, heat and radar. The type of radiation associated with uranium is ionising radiation.

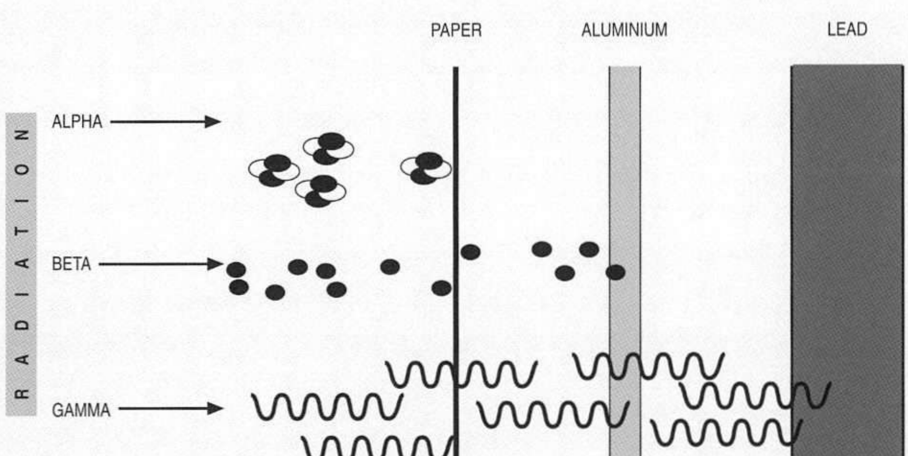
Ionising radiation has the ability to 'ionise' matter that it hits. This means that it has the ability to break the bonds that bind electrons to atoms.

There are three main types of ionising radiation: alpha, beta and gamma. Each of these carries energy away from the radioactive element and gives up that energy when it interacts with matter in its path, as shown in Figure N.2. Alpha radiation carries more energy than beta or gamma, but alpha radiation does not travel very far, even in air. It can be stopped by a few sheets of paper. Beta radiation carries more energy than gamma radiation but it can be stopped by a thin sheet of aluminium. Gamma radiation carries the least amount of energy but it is very penetrating. Most gamma rays pass straight through any matter that is in their way. It takes very dense material, such as concrete or lead, to stop gamma radiation.

N4 RADIATION DOSES

A radiation dose is simply a measure of how much energy is absorbed when ionising radiation hits tissues in the body. In the previous paragraph, it was pointed out that the three different types of ionising radiation carry different amounts of energy and that each type is more, or less, penetrating than the others. This means that, per unit exposure, alpha radiation may not have the same biological effect as gamma radiation.

Alpha radiation does not penetrate very far in tissue, but this means that the energy it deposits is spread over a very short distance. Beta radiation penetrates further than alpha radiation and the energy it deposits is spread over a longer distance. Gamma radiation penetrates furthest and deposits its energy over a much longer distance. Figure N.3 illustrates these differences.

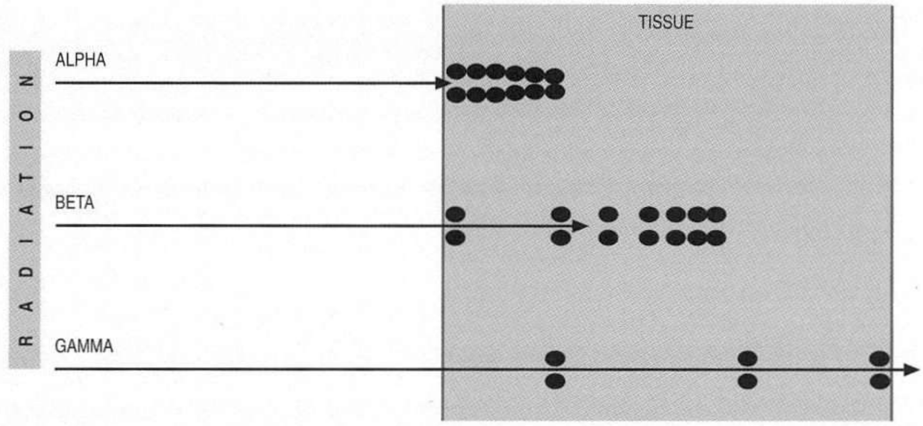


In this figure, radiation from the left is absorbed by different types of material.

Alpha particles do not travel far, have little penetrating power, and are stopped by paper.

Beta particles are stopped by an aluminium sheet, and gamma rays are stopped by concrete or lead.

FIGURE N.2
THE PENETRATING POWER OF THE THREE MAIN TYPES OF RADIATION



In this figure, radiation is shown entering tissue from the left. It gives up its energy by ionising the matter it hits. Ionised atoms or molecules are represented by the black circles.

Alpha particles give up their energy over a short distance.

Beta particles give up their energy over a longer distance, and gamma rays may pass right through matter while only giving up part of their energy.

The harm that radiation does is partially due to this 'Linear Energy Transfer'. Alpha radiation has the highest LET, then beta, and lastly, gamma.

FIGURE N.3
THE LINEAR ENERGY TRANSFER OF THE THREE MAIN TYPES OF RADIATION

Alpha radiation therefore has the potential to be the most destructive type of radiation, but its source has to be close to tissue in the body. In fact, alpha radiation will not penetrate skin, so the source of the radiation must be inside the body for it to irradiate sensitive cells.

Beta radiation will penetrate skin, but it will not penetrate very far. Most of the dose from external beta radiation is a 'skin dose' because that is where the energy is deposited, but beta radiation can contribute significantly to internal doses if the source is within the body.

Gamma radiation penetrates most matter, so the source of gamma radiation can be either inside the body or outside.

N5 THE EFFECT OF RADIATION

The energy that ionising radiation deposits in the body has the ability to break the bonds between atoms. Atoms and molecules are bound together by the electrons that surround them. If these bonds are broken, the atoms and molecules behave in ways that are different from the ways they normally behave.

In most cases, breaks do not matter to the functioning of the body. Breaks are either repaired or they occur in places where they do no harm. If, however, the break occurs in special molecules that control the way in which cells work, the break can be serious. The cell can stop working, start working in a destructive way, or it can die.

If a cell stops working, or dies, there are usually many other cells of the same type to take over, so the loss of a few of these cells will not affect the functioning of the body. If the cell is damaged in such a way as to make it start working destructively, it can lead to cancer. If the cell happens to be one of those that is used in reproduction, there is a chance that the damage could be passed on to children born from these damaged cells.

The main types of damage that we are therefore interested in, and we want to prevent, are cancer and genetic effects.

N6 RISKS ASSOCIATED WITH RADIATION

Because each individual instance of alpha, beta or gamma radiation has the potential to break a bond in a molecule, it is often said that 'there is no safe dose of radiation'. However, there must be a certain amount of radiation that does no harm, since millions upon millions of ionisation events occur in our bodies every day but we do not all get cancer. Similarly, reproductive cells receive radiation doses all the time but relatively few babies are born with genetic defects.

Nobody knows the precise way that determines if a cancer will develop or if a baby will be born with a genetic defect. It is therefore better to make sure that all doses of radiation are kept to a minimum. For a linear dose–effect relationship, the harm that radiation does is said to be directly proportional to the amount of radiation received, or the dose. Dose–effect relationships are discussed in Section N12.

Large radiation doses have a greater risk of causing cancer than small ones. There is evidence for this in studies on both humans and animals. People who have been exposed to large radiation doses are more likely to get cancer than people who have not. Radiation accidents and the atomic bombing of Hiroshima and Nagasaki in Japan at the end of the Second World War have provided evidence of the cancers caused by quite large radiation doses. The evidence for small radiation doses is more difficult to collect because everyone receives small radiation doses and because radiation is not the only agent that can cause cancer.

N7 BACKGROUND DOSES OF RADIATION

Nearly everything in the world is radioactive to some degree. This means that we all receive a dose of radiation. This type of radiation is called 'background' radiation, and it varies with geographic location, diet and lifestyle. The average yearly dose from background radiation is about 2.5 units, but some people receive more than double this amount each year, while others receive slightly less. The various units for expressing radiation dose are discussed in Section N11.

In addition to natural background radiation people are exposed to additional radiation from such sources as medical therapy and diagnosis. While the range of individual doses from medicine is great and depends mainly on the medical services available to people in different countries, the average for industrialised countries is between 0.4 and 1.0 unit per year. Other non-occupational practices that expose people to radiation, in addition to background, include air travel, coal-burning in power stations and discharges from nuclear power stations. Taken together, these sources contribute only 0.03 units of radiation per year.

There are laws in most countries that prevent people who work with radiation, such as nuclear power station operators, X-ray technicians and uranium miners, from receiving radiation doses that exceed certain limits. In Australia, people who are not employed as radiation workers are not allowed to receive more than one extra radiation dose unit per year.

Most radiation workers in Australia are subject to a subsidiary limit, or 'dose constraint', that restricts their dose to below 5 radiation dose units per year from their work. For a few radiation workers (called 'designated' workers) the average annual dose limit is 20 units per year, averaged over five years, or 50 units in any single year. Table N.1 compares the size of radiation doses from various activities.

Table N.1 Magnitude of radiation doses from various sources

Activity	Reason/source	Average dose	Range of radiation doses
Air travel (return trip from Sydney to Los Angeles)	Greater cosmic radiation at high altitudes	0.05 units for each trip	0.02 units if travelling by Concorde (the trip will be shorter).
Medical uses of radiation	X-rays, nuclear medicine and radiotherapy	0.4 units per year	Zero to hundreds of units —most people receive no medical radiation in a year, but some receive several hundred units when they are being treated by radiotherapy.
Uranium miners	Uranium ore		
Underground		6–8 units per year	0.1–8 units depending on the grade of the ore and the job.
Open-cut mines		2–5 units per year	
Processing plants		1.5 units per year	

N8 RADIATION DOSE PATHWAYS

Of the three main types of radiation associated with uranium, alpha radiation does not penetrate very far compared with gamma radiation. This means that for alpha radiation to have an effect it must come from inside the body.

In uranium mining and milling, the main way in which a source of alpha radiation can get into the body is when it is breathed in as dust. Small amounts may be taken in through the mouth, for example by dirty hands, but insoluble material taken in this way passes right though the body and is eliminated. Ingested material that contains soluble radionuclides (radioactive isotopes) contributes to the radiation dose, but this pathway is a minor contributor at uranium mines and processing plants. Dust that is breathed in may stay in the lungs for a long time during which it will be giving the lining of the lungs a radiation dose. Dust lodged in the lungs can also dissolve, releasing radionuclides that are then able to move to other organs and tissues in the body, thereby irradiating organs other than the lungs themselves.

A source of gamma radiation need not be inside the body to have an effect. Any radioactive material that emits gamma radiation and is near a person will give that person a continuous radiation dose for as long as the source and the person remain in proximity.

Beta radiation mainly affects the skin and the tissue that lies immediately underneath the skin, but can be an important source of radiation dose from internally deposited radionuclides.

N9 THE MEASUREMENT OF RADIATION

A radiation dose is a measure of the energy deposited in tissues or organs in the body. This quantity cannot be measured directly. Indirect means are used to assess the types and amounts of radiation or radioactive material to which people are exposed. Models are then used to convert the exposures into expressions of dose.

For gamma radiation in industrial situations, small detectors which can measure radiation exposures over periods of time are worn on employees' clothes. A spot reading can also be made with a suitably calibrated gamma radiation meter; this reading can then be multiplied by the number of hours the person spends near a radiation source to give an estimate of the total radiation exposure for a particular period.

Exposure to alpha radiation comes about mainly through the inhalation of material containing radionuclides (such as dust) or the inhalation of air containing radioactive gas and its decay products (such as radon and radon decay products). The level of exposure to alpha radiation is assessed by passing air through filters that collect the dust or the radon decay products. The exposure is then converted into an expression of dose by calculating the quantity of air breathed (and therefore the quantity of dust and radon decay products inhaled) and by multiplying the result by a conversion factor derived from physiological models (for dust) and epidemiological evidence (for radon decay products). The conversion factors take into account not only the alpha decay but also the decay by beta and gamma emissions of the radionuclides in air.

N10 REDUCING EXPOSURE

Radiation cannot be avoided altogether, but there are ways to avoid radiation in the mining and milling of uranium ore. The reduction of radiation exposure starts with the design of facilities and operating procedures. Each new process or procedure is assessed for safety and reduction of risk (safety optimisation). Once a process is in operation, a programme of measurement is conducted, with records being kept and the data analysed to extract information. Reports are used both internally and externally by the statutory authorities to assess the effectiveness of control measures.

Most of the radiation dose in modern open-cut uranium mines comes from gamma radiation. Exposure to gamma radiation is reduced by the shielding effect of the steel of mining vehicles, by the use of shielding materials such as barren rock, and by making sure that the time people spend in areas of high grade ore is as short as possible. Radiation from radon decay products is effectively controlled by the natural ventilation capacity of the atmosphere.

In underground mines, artificial ventilation methods are used to reduce exposure to radon decay products. The design of underground ventilation systems is such that air with low radon decay product concentrations is supplied directly to workplaces. This air accumulates radon decay products during the time it spends underground, and is vented through tunnels and ventilation shafts in which people spend little or no time.

Radiation from dust is avoided by reducing and controlling the number of dusty operations. Drilling can often be dusty, but there are ways of making less dust; for example, rigs can be fitted with dust collectors, the cabins can be air-conditioned, and drilling can be done 'wet'. If it is not possible to make less dust in the first place, masks or special helmets that filter out the dust can be worn.

All types of radiation can be reduced by moving away from the radioactive material when it is not necessary to be near it. Meal and rest breaks are spent away from production and development areas to avoid spending unnecessary time near the radioactive material. Similarly, clothes that have become contaminated with dust or mud are cleaned at the end of the shift and are not worn in the accommodation and mess areas.

A programme for reducing exposure can only succeed if personnel are aware of the risks and the prevention measures. An integral part of such programmes, therefore, is the induction and training of personnel by professional safety staff.

N11 RADIATION UNITS

There are a number of different units of measurement for radiation, each with a specific meaning. For the purposes of this explanation, there are three important units:

Absorbed dose: This is a measure of the mean energy imparted by ionising radiation to a volume of tissue. The absorbed dose, *D*, is defined as:

$$D = \frac{d\bar{\varepsilon}}{dm}$$

where $d\varepsilon$ is the mean energy imparted by ionising radiation to the matter in a volume element of mass dm. The special name for the unit of absorbed dose is the gray (Gy); one gray is equal to one joule per kilogram.

Effective dose: The probability of an effect occurring and the dose are found to vary with the organ or tissue irradiated. In order to account for this, a quantity called the 'effective dose' is used. This indicates the combination of different doses to several different tissues in a way that is likely to correlate well with the total probability of an effect in the person as a whole. Each organ and tissue is assigned a weighting factor related to its radiosensitivity. The special name for the unit of effective dose is the sievert (Sv); one sievert is equal to one joule per kilogram. The effective dose, E, is the sum of the weighted equivalent doses in all the tissues and organs of the body, and may be expressed as:

$$E = \sum_{T} w_T . H_T$$

where H_T is the equivalent dose in tissue or organ T and w_T is the weighting factor for tissue or organ T.

The weighting factors currently used are shown in Table N.2.

Committed effective dose: When radioactive material is taken into the body, the dose is not delivered all at one time, but is spread over the entire time that the radioactive material remains in the body, or remains radioactive. An initial intake means that one is committed to receiving a radiation dose. The 'committed effective dose' is therefore the integral of the radiation dose over time. When the time is not known, a period of fifty years is implied for adults and seventy years for children.

Table N.2 Tissue weighting factors

Tissue or organ	Tissue weighting factor
Gonads	0.20
Bone marrow (red)	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Bladder	0.05
Breast	0.05
Liver	0.05
Oesophagus	0.05
Thyroid	0.05
Skin	0.01
Bone surface	0.01
Remainder	0.05

Source: International Commission on Radiological Protection 1991.

N12 RADIATION RISK ASSESSMENT

Evidence for the risks associated with exposure to radiation comes from numerous studies of both human populations and animals. Perhaps the most comprehensive study is that which continues into the health of the survivors of the atomic bombing of Hiroshima and Nagasaki during the Second World War. Other studies include groups of people exposed to radiation in medicine for therapeutic or diagnostic reasons and small groups of people exposed accidentally.

The epidemiological studies attempt to determine the excess number of health effects, over and above the underlying rate of these health effects in the population under study, which can be attributed to a known or estimated radiation exposure. A very wide range of health effects has been studied, including cancers of various types, genetic effects, mental health aspects and immune system suppression.

Recently, new information about the carcinogenic effects of radiation has come from continuing studies of Japanese atomic bomb survivors; patients irradiated for ankylosing spondylitis, cancer of the uterine cervix and tinea capitus; workers in various occupations; and populations living in areas of high natural background radiation. This new information has prompted a revision of the risk estimates for the carcinogenic effects of radiation.

In short, the new information has meant that, per unit dose, the carcinogenic effects of atomic bomb radiation are now estimated to be somewhat larger than previously thought. The main reasons for this finding are that the types and quantities of radiations produced by the two bombs have been revised, and there have been several more years of follow-up of the survivors. Additional information has been gained from studies into the effect of the rate at which the dose is delivered on the number of detrimental effects observed.

A high dose delivered in a short period has a disproportionately greater effect than the same dose delivered over a longer period; thus a departure from linearity is indicated under these circumstances. A reduction factor, called the dose and dose rate effectiveness factor (DDREF) has been recommended by the International Commission on Radiological Protection (ICRP) (1991). This factor has been included in the probability coefficients for all equivalent doses resulting from absorbed doses below 0.2 Gy and from higher absorbed doses when the dose rate is less than 0.1 Gy per hour.

Studies continue to find that the dose–effect relationship for overall mortality from cancers other than leukaemia shows no significant departure from linearity over the range from 0 to 3 Gy (with the qualification for DDREF outlined above). For leukaemia and some solid cancers in particular organs, the dose–effect relationship is more consistent with a linear–quadratic or quadratic function. Figure N.4 illustrates these relationships.

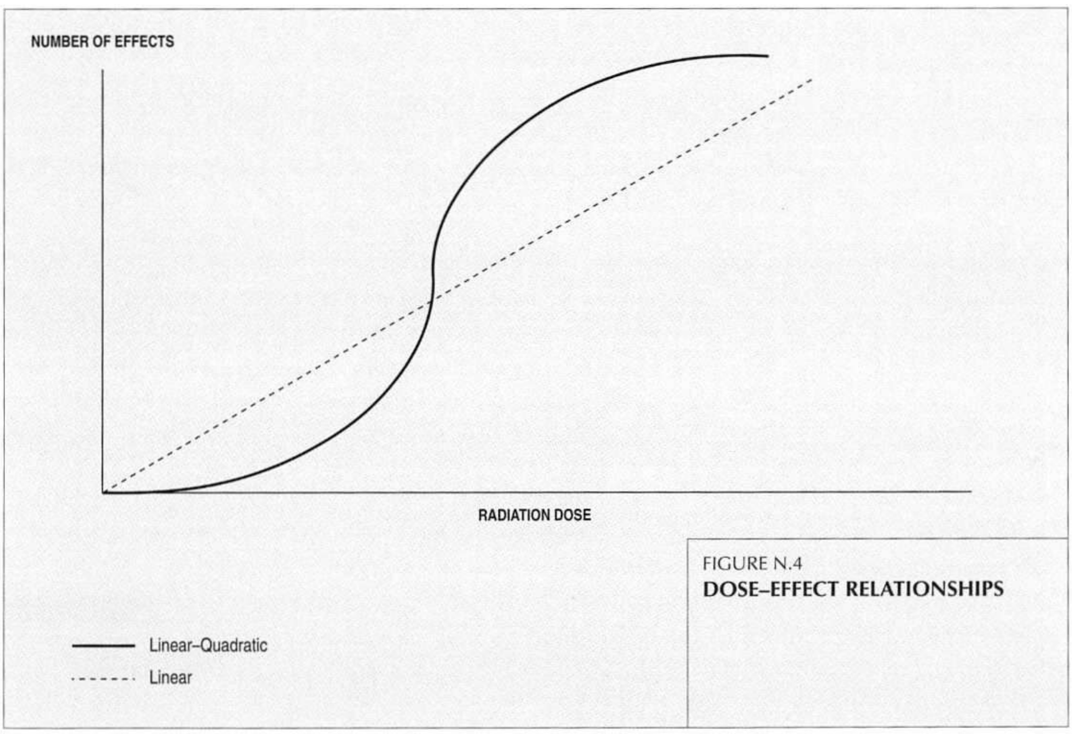


FIGURE N.4
DOSE–EFFECT RELATIONSHIPS

Care should be observed when interpreting the dose–effect curves. At low doses there is insufficient evidence for categorical statements regarding the risks of radiation. The Health Physics Society has recently published its position statement on low doses (Health Physics Society 1996). The statement is reproduced below.

> In accordance with current knowledge of radiation health risks, the Health Physics Society recommends against quantitative estimation of health risk below an individual dose of 50 mSv in one year, or a lifetime dose of 100 mSv in addition to background radiation. Risk estimation in this dose range should be strictly qualitative accentuating a range of hypothetical health outcomes with an emphasis on the likely possibility of zero adverse effects. The current philosophy of radiation protection is based on the assumption that any radiation dose, no matter how small, may result in human health effects, such as cancer and hereditary genetic damage. There is substantial and convincing scientific evidence for health risks at high dose. Below 100 mSv (which includes occupational and environmental exposures) the risks of health effects are either too small to be observed or are non-existent.

The ICRP has calculated and published the risk coefficients for radiation (Table N.3).

Table N.3 Probability coefficients for health effects

Exposed population	Number of effects per mSv			
	Fatal cancer	Non-fatal cancer	Severe hereditary effects	**Total**
Adult workers	0.00004	0.000008	0.000008	**0.000056**
Whole population	0.00005	0.00001	0.000013	**0.000073**

After International Commission on Radiological Protection 1991.

Having quantified the risk per unit exposure to radiation, it is important to assess the level at which the risk (and therefore the dose) is acceptable. Here social factors and the perception of risk need to be accounted for. The word 'risk' is somewhat misleading in the practice of radiation protection in that it implies the threat of an undesirable effect, including both the probability and the character of the event. In this sense, risk is equivalent to 'hazard'. In radiation protection, the word risk usually means the mathematical expectation of the magnitude of the undesirable consequence, i.e. the product of the probability and the consequence of the event.

The ICRP uses 'death probability rate' rather than 'mortality rate' in its presentation of risk comparisons. This is because ICRP calculations are based on the attributable lifetime probability of death related to the average individual, rather than the observed or expected number of deaths per 100,000 persons.

The total probability of death is 100%, and cannot be increased. Exposure to radiation will not change the total probability, but it may change the distribution of the probable causes of death. Any increment that a new source of risk causes is an increment in death probability rate at any given age. The death probability rate at various ages is available in most countries, and provides the 'background' against which incremental risks can be judged.

Care must be taken, however, because exposure to radiation at low dose and low dose rates does not cause immediate death. Death from cancer may be delayed many years and will occur when the background death probability rate is also high (the death probability rate for older people is higher than for young people). Any country wishing to set dose limits (and therefore, limits for attributable lifetime death probability) will of course consider not only scientific conclusions but also subjective assessments.

In the past the ICRP has recommended the setting of radiation dose limits at a point where the calculated risks associated with radiation and the actuarial risks assocated with various 'safe' industries are equivalent. In other words, working in an occupation that exposed a person to radiation would be as safe as working in a manufacturing industry.

The ICRP now recommends setting dose limits at the border between 'just tolerable' and 'unacceptable' risk. In order to arrive at the most recent occupational radiation limits, the ICRP used test values of annual radiation doses and calculated the associated risks. An objective and subjective assessment of the risks was then undertaken to determine which value of dose limit would meet the criterion of being 'just tolerable'.

The assessment took into account the risk of mortality and morbidity and was weighted for hereditary factors. Table N.4 shows the results of the assessments performed at three annual dose levels.

Table N.4 Attributes of detriment due to exposure of the working population

Annual effective dose	10 mSv	20 mSv	50 mSv
Probability of attributable death (%)	1.8	3.6	8.6
Weighted contribution from non-fatal cancer (%)	0.4	0.7	1.7
Weighted contribution from hereditary effects (%)	0.4	0.7	1.7
Aggregated detriment (%)	2.5	5	12
Time lost if death occurs (years)	13	13	13
Mean loss of life expectancy at age 18 (years)	0.2	0.5	1.1

Source: International Commission on Radiological Protection 1991.

From this assessment, the ICRP recommended that an annual average dose of 20 mSv would provide the risk value equivalent to the border between 'just tolerable' and 'unacceptable'.

N13 REGULATION OF RADIATION PROTECTION

The risks associated with radiation are known and quantified or estimated from models. The objective of radiation protection is to limit the number of adverse health effects by the application of a formal, structured programme of measurements, controls and analyses. The philosophy underlying this programme has been encapsulated by the ICRP in three principles (International Commission on Radiological Protection 1991):

- No practice involving exposures to radiation should be adopted unless it produces sufficient benefit to the exposed individuals or to society to offset the radiation detriment it causes. (This is called the justification of a practice.)
- In relation to any particular source within a practice, the magnitude of individual doses, the number of people exposed, and the likelihood of incurring exposures where these are not certain to be received, should all be kept as low as is reasonably achievable, with economic and social factors being taken into account. This procedure should be constrained by restrictions on the doses to individuals (dose constraints), or the risk to individuals in the case of potential exposures (risk constraints), so as to limit the inequity likely to result from the inherent economic and social judgments. (This is called the optimisation of protection.)
- The exposure of individuals resulting from the combination of all the relevant practices should be subject to dose limits, or to some control of risk in the case of potential exposures. These are aimed at ensuring that no individual is exposed to radiation risks that are judged to be unacceptable from these practices in any normal circumstances. Not all sources are susceptible of control by action at the source and it is necessary to specify the sources to be included as relevant before selecting a dose limit. (This is called individual dose and risk limitation.)

Australian radiation protection legislation is based on these principles. While the wording and the legal instruments vary from jurisdiction to jurisdiction, the dose limits are the same as those recommended by the ICRP, and the National Health and Medical Research Council (NHMRC) has endorsed their use. States and Territories are responsible for the promulgation and administration of legislation for radiation safety within their borders.

The system of approvals to operate a mine and processing plant includes provision for conditions to be placed on the approvals. A common condition of approval is the application of the Commonwealth Codes of Practice on radiation safety, disposal of radioactive mine wastes and the transport of radioactive materials.

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APPENDIX O

ECONOMICS

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APPENDIX O

ECONOMICS

O1 INTRODUCTION

The planned expansion to Olympic Dam is a large project in the context of the small, regional economy of South Australia. A project of this magnitude is likely to have effects on the State and national economies that extend beyond cost data directly relevant to the project. For this reason, Kinhill Economics has subcontracted the South Australian Centre for Economic Studies (the Centre) to undertake a study of the economy-wide effects of the project.

Using data supplied by Kinhill, the Centre has projected the effects of a construction phase of the announced expansion to Olympic Dam. The Centre used its computable general equilibrium (CGE) model of the South Australian and Australian economies, FEDERAL–SA, to project the economy-wide effects of the Olympic Dam expansion.

Section O5 describes FEDERAL–SA in more detail. The model contains 65 industries in each of the two 'regions'. Each industry produces a single commodity. Models of this sort capture the direct plus indirect effects of changes in demands associated with the construction phase in South Australia. The model also captures the effects that the phase will have on the rest of Australia. Within FEDERAL–SA, the Olympic Dam project directly affects two industries, 'non-ferrous metal ores' and 'non-ferrous metal products'.

The Centre projected the construction phase, as reported in Section O2, using two different assumptions about the labour market. A third scenario, in Section O3, deals with the operational phase of the project. The results presented in Sections O2 and O3 represent the modelled changes across the South Australian and Australian economies, from a base case of 1996–97 operations at Olympic Dam.

Using tentative available information, the Centre examines the effects of two further scenarios in Section O4. These scenarios deal with the possible further expansion of the mineral extracting and copper processing capacity of Olympic Dam to 350,000 t/a of copper. It should be noted that the WMC board has made no formal decision to proceed with this further expansion at the present time. In Section O4, the base case is the operational phase of the 200,000 t/a scenario at around 2006–07.

Changes in gross state product (GSP) of South Australia and national gross domestic product (GDP) are modelled. South Australia's current base case GSP is approximately $32 billion, while Australia's current base case GDP is approximately $450 billion. Base case consumption for South Australia is $15.1 billion and for Australia, $181.6 billion.

O2 THE CONSTRUCTION PHASE

The construction phase of the extension to Olympic Dam will entail $1,477 million of total expenditure over two and a half years. The latest direct employment number estimated by WMC for the construction phase is 1,300. The Centre based its modelling results on 1,100 jobs being created. The actual direct number employed is less critical to the total employment outcome projected for South Australia and Australia than what we assume within the model about the labour market, as is evident from a comparison of the employment outcomes for the first and second scenarios.

In addition, there will be employment created indirectly. That is, additional demands for goods and services associated with the construction phase will create jobs in other industries. The project entails construction for mineral extraction plus processing. The construction phase was originally planned to proceed over a two and a half year period, ending in 1999–2000; however, WMC is implementing an accelerated programme which should shorten the construction period to less than two years.

WMC has indicated that construction costs specific to the mine at Olympic Dam amount to $373 million, with a further $934 million specific to processing. In addition, there are proposed infrastructure costs of $135 million and township costs of $36 million. The Centre split these two items between the mining industry and the processing industry. These last two items are small in comparison with the main construction expenditures. Therefore, we may understate the impact on 'residential construction' slightly within our projected results, with negligible change in broader sectoral or macroeconomic results.

In the construction phase, the Centre assumes that in response to expenditures associated with the project other industries have insufficient time to respond through adjustments to capital stocks. This is modelled by constraining capital, keeping capital stocks in each industry constant.

The Centre used two different assumptions in its treatment of the labour market. In the first, the national employment level does not differ from a base case. That is, workers could migrate between regions in response to changes in relative economic opportunities, without any change in the number of employed and unemployed at the national level. By placing that constraint at the national level, but not at the State level, it is possible to create jobs in South Australia within the model, but at the expense of jobs interstate. This gives a lower bound estimate of the number of jobs likely to be created by the project.

In the second set of assumptions, the national pool of employed labour may grow or shrink in response to a stimulus. In the second set, the income and employment gains from the investment phase are substantially larger than in the first set. This is because lifting constraints on the modelling framework magnifies gains. This gives us an upper bound estimate of the number of jobs likely to be created. We might treat our two assumptions as extremes, and therefore expect actual results to lie somewhere between the projected results for each.

The different treatments of labour and capital form part of the 'closure' used in a particular scenario. The closure is a list of variables within the model which are constant or 'exogenous' during a simulation, and those which vary or are 'endogenous'.

In addition to spending $1,477 million over two to two and a half years, WMC has also indicated that it expects some increase in production during this phase. The Centre has modelled this increase on an average annual basis in each of the two settings. (It should be noted that the Centre initially modelled this as a two-and-a-half-year project. The implementation of the two-year schedule means that short-term impacts may be marginally larger than the Centre has modelled, but they will also be of a shorter duration.)

Construction phase: first scenario, 200,000 t/a capacity—national employment constrained

Real GSP in South Australia increases by 0.4% (Table O.1), or about $120 million. This gain is smaller than the proposed average annual expenditure of $590 million (i.e. $1,477 million over two and a half years), representing mainly the direct value added component of construction activity.

That the real GSP gain is significantly smaller than the additional investment is, in part, a consequence of the cost squeeze imposed on industries throughout the economy. The increased demands of construction raise prices for consumers and other industries purchasing goods and services. Therefore the gains that industries experience through increased purchases for investment purposes are partly offset by rising prices. If the direct demands of Olympic Dam for the output of an industry dominate, the output of the industry increases. The converse applies if the cost squeeze through higher input prices on that industry dominates.

Further, at a constant nominal exchange rate, increased demands for goods and services associated with the operational phase induce a real exchange rate appreciation through increased prices. The increase in the consumer price index (CPI) for South Australia is 0.6%, while that for the rest of Australia is 0.4% (Table O.1). This reduces the international competitiveness of export-oriented industries, imposing a small squeeze on such industries. FEDERAL–SA assumes that all industries are constant cost (i.e. unit costs do not fall as scale increases). In industries where scale economies are important, such as 'electricity', as cited in our discussion of the operational phase, FEDERAL–SA will tend to exaggerate the price increases and associated cost squeeze on industries.

At the macroeconomic level, the additional activity associated with the construction phase draws labour into South Australia. The State's work force increases by 0.3% (Table O.1) or around 1,750 jobs in total. This compares with the direct employment requirement of 1,300 workers during construction. Due to our assumption that the national pool of employment is constant, regardless of the scenario, this is a lower bound estimate of the employment effect.

Due to the direct impact of the construction project, real investment (based on the GSP rather than the investment deflator) increases by 3.2%. *[The investment deflator is based on returns to capital in typical years. A construction phase involves atypical returns for the period of the phase. Hence, we use another deflator.]* Real consumption in South Australia increases by 0.1% ($21 million).

Table O.1 Macroeconomic effects of Olympic Dam construction phase—national employment constrained

Expenditure side		% change from base case	Income side		% change from base case
Real GSP	– SA	0.39	Returns to capital (nom.)	– SA	1.04
	– rest of Aust.	–0.03		– rest of Aust.	0.41
Real GDP	– national	0.00	Returns to labour (nom.)	– SA	0.79
				– rest of Aust.	0.50
GSP deflator	– SA	0.61			
	– rest of Aust.	0.44	Consumer price index	– SA	0.57
				– rest of Aust.	0.39
GDP deflator		0.45		– Australia	0.41
Private investment (real)	– SA	3.23	Number employed	– SA	0.26
	– rest of Aust.	0.20		– rest of Aust.	–0.02
Real consumption	– SA	0.14		– Australia	0.00
	– rest of Aust.	0.04			
	– Australia	0.05			
Balance of trade (Australia) = –$326 million					

Source: FEDERAL–SA projections.

In a two-region or multi-region model, construction phases tend to follow a zero-sum game, that is, gains in one region or industry tend to be at the expense of other regions or industries. Essentially, we are modelling a level of construction that is above a region's usual share of national investment activity. The region where additional activity takes place experiences increases in real income and employment. Other regions lose out because construction activity in a CGE framework entails a diversion of resources from other activities, through price competition, while the effect nationally approximates zero. In a model with increasing rather than constant returns to scale as applies in FEDERAL–SA, price effects would be weakened but not eliminated.

The rest of Australia loses, in terms of real GSP, from the construction phase if we assume that labour is constrained at the national level. Increased nominal income earned by labour (0.8%) and capital (1.0%) in the rest of Australia is small in real terms, based on the GSP deflator of 0.6%. The real GSP in the rest of Australia decreases slightly, with negligible change in the national GDP. That the latter is not slightly negative is due to the small productivity gain ascribed to 'non-ferrous metals' during the construction phase.

In fiscal (public revenue and expenditure) terms, the construction phase benefits South Australia, with the public sector borrowing requirement (PSBR) decreasing by $4 million. But due to payments being indexed to CPI, the PSBRs of the Commonwealth ($98 million) and other State governments ($24 million) increase. Revenues decrease in the rest of the economy due to the small decrease in economic activity outside South Australia. The Centre did not model the $3.7 million medical facility to be paid for by the South Australian Government. On an annualised basis, this is small compared with the projected change in PSBR.

We can view the pattern of gains and losses across the economy from the broad sectoral outcomes for output and export volumes (Table O.2). In South Australia, the gains to services are large, in dollar terms, compared with the losses in other sectors. Interstate, there are small gains in services that do not offset the losses elsewhere. The volume of exports decreases, indicating a switch from exports to domestic purchases. This contributes to a deterioration in the national balance of trade (net exports decrease by $326 million).

Table O.2 Broad sectoral effects of Olympic Dam construction phase—national employment constrained

	South Australia % change from base case		Rest of Australia % change from base case	
	Output	Overseas exports	Output	Overseas exports
Agriculture	–0.43	–0.64	–0.30	–0.53
Mining	–0.34	–0.65	–0.23	–0.35
Manufacturing	–0.07	–0.98	–0.07	–0.71
Services	0.23	–	0.02	–

Source: FEDERAL–SA projections.

At the industry level, the biggest gainers are the 'non-ferrous metal products' and 'other construction' industries in South Australia (Table O.3). The former is due to productivity gains already realised, based on information on expanded output provided by WMC, during the construction phase. The latter is a direct consequence of the construction phase. Some manufacturers increase their output due to increased demands for construction materials. Generally, other service industries, including 'finance', 'electricity' and 'road transport', gain from the additional construction activity.

Construction phase: second scenario, 200,000 t/a capacity—national employment varies

In the first scenario, both labour and capital stocks were constrained at the national level. We can question a labour constraint during times of high unemployment, particularly in South Australia where construction activity has been depressed over the past few years. Nevertheless, labour mobility may be an issue when dealing with a project in a remote region. Attracting workers is likely to entail higher costs than in less remote regions, which may constrain the employment response. But the Centre believes it is appropriate to lift the national constraint to test the sensitivity of our assumptions and give some measure of the possible national employment effect.

Table O.3 Industry level effects of Olympic Dam construction phase—national employment constrained

	Output	Producer price	Export volume (overseas)	Rate of return on capital	Employment
	% change from base case				
INDUSTRY (65 SECTOR) SA					
Ferrous metal ores	–0.17	0.06	–0.32	–2.42	–0.75
Non-ferrous metal ores	–1.12	1.12	–2.54	na	–0.90
Coal, oil and gas	–0.35	0.32	–1.07	–3.89	–1.15
Minerals n.e.c.*	0.14	0.68	–	0.80	0.28
Services to mining	–0.15	0.71	–	–0.82	–0.30
Basic iron and steel	0.06	0.47	–	0.69	0.11
Non-ferrous metal products	2.66	–2.69	4.29	na	0.63
Residential construction	0.59	0.70	–	3.29	0.86
Other construction	2.34	0.82	–	12.26	2.57
Road transport	0.05	0.58	–	0.69	0.07
Rail transport	–0.18	0.53	–	–1.19	–0.24
Finance (inc. software)	0.38	1.31	–	2.76	0.86
Electricity	0.12	0.59	–	1.03	0.32
INDUSTRY (65 SECTOR) INTERSTATE					
Ferrous metal ores	–0.22	–0.09	–0.27	–2.58	–0.88
Non-ferrous metal ores	–0.29	–0.01	–0.37	–3.75	–1.19
Coal, oil and gas	–0.22	–0.08	–0.40	–2.02	–0.69
Minerals n.e.c.*	0.04	0.46	–	0.66	0.08
Services to mining	–0.24	0.31	–	–1.39	–0.53
Basic iron and steel	0.06	0.36	–	0.78	0.10
Non-ferrous metal products	–0.18	–0.01	–0.05	–1.54	–0.57
Residential construction	0.25	0.55	–	1.58	–0.02
Other construction	0.15	0.46	–	1.03	–0.02
Road transport	–0.08	0.44	–	0.04	–0.11
Rail transport	–0.16	0.38	–	–0.53	–0.22
Finance (inc. software)	0.00	0.50	–	0.25	0.01
Electricity	–0.02	0.35	–	0.09	–0.06

Source: FEDERAL–SA projections.
**'not elsewhere classified'.*

In this setting, real GSP in South Australia increases by 0.5%, or about $150 million. Real consumption increases by 0.2% ($30 million). Real investment increases by 3.3%. We project a larger employment effect in South Australia, with the project resulting in an increase of 0.37%, or 2,500 jobs. Nationally, employment increases by 0.07%, implying that another 3,000 jobs are created outside South Australia (Table O.4). This is our upper bound estimate of the potential employment increase.

Lifting the constraint on labour results in smaller price effects. The increase in CPI for South Australia is 0.5%, while that for the rest of Australia is 0.3%.

In this setting, in which employment can increase at the national level, the rest of Australia gains, in terms of real GSP, from the construction phase. Real GSP in the rest of Australia increases slightly, with a national real GDP increase of less than 0.1% ($180 million). This time, the balance of trade deteriorates by the smaller figure of $239 million.

The PSBR of the State governments decreases by $9 million for South Australia and $16 million in the rest of Australia. In particular, payroll tax revenues increase by 0.6% ($3 million) and 0.3% ($21 million) respectively. The Commonwealth Government's PSBR increases by $32 million due to increases in CPI. By assumption, a number of Commonwealth expenditures within the model are linked to CPI. Nominal wage and employment increases drive these outcomes. South Australia's nominal labour income (returns to labour) increases by 0.6%, for example, which is larger than the employment increase of 0.4%, indicating a rise in real wages.

Table O.4 Macroeconomic effects of Olympic Dam construction phase—national employment varies

Expenditure side		% change from base case	Income side		% change from base case
Real GSP	– SA	0.47	Returns to capital (nom.)	– SA	1.05
	– rest of Aust.	0.01		– rest of Aust.	0.34
Real GDP	– national	0.04	Returns to labour (nom.)	– SA	0.63
				– rest of Aust.	0.31
GSP deflator	– SA	0.46			
	– rest of Aust.	0.27	Consumer price index	– SA	0.45
				– rest of Aust.	0.25
GDP deflator		0.28		– Australia	0.26
Investment (real)	– SA	3.33			
	– rest of Aust.	0.23	Number employed	– SA	0.37
				– rest of Aust.	0.05
Real consumption	– SA	0.18		– Australia	0.07
	– rest of Aust.	0.05			
	– Australia	0.06			
Balance of trade (Australia) = –$239 million					

Source: FEDERAL–SA projections.

At the broad sectoral level, while the pattern of gains and losses is similar to the first scenario, the magnitudes of losses are smaller. In particular, the smaller real exchange rate effect induces smaller losses in exports (Table O.5). Generally, with the smaller cost squeeze, losses are smaller in the second scenario. Manufacturing output, for example, increases slightly in the second scenario instead of decreasing.

Table O.5 Broad sectoral effects of Olympic Dam construction phase—national employment varies

	South Australia % change from base case		Rest of Australia % change from base case	
	Output	Overseas exports	Output	Overseas exports
Agriculture	–0.27	–0.41	–0.16	–0.30
Mining	–0.22	–0.58	–0.13	–0.23
Manufacturing	0.05	–0.60	0.01	–0.43
Services	0.29	–	0.04	–

Source: FEDERAL–SA projections.

A similar pattern is evident at the industry level as in the first version of the construction scenario. Again, the biggest winners are the 'non-ferrous metal products' and 'other construction' industries in South Australia. And virtually all service industries gain from the project (Table O.6).

In summary, lifting the employment constraint provides, as expected, a larger employment effect in South Australia and an increase in employment interstate. Prices increase by a smaller amount than in the labour-constrained scenario. Income and output gains are slightly larger in the second scenario.

Table O.6 Industry level effects of construction phase—national employment varies

	Output	Producer price	Export volume (overseas)	Rate of return on capital	Employment
	% change from base case				
INDUSTRY (65 SECTOR) SA					
Ferrous metal ores	–0.12	0.07	–0.26	–1.84	–0.50
Non-ferrous metal ores	–0.98	1.13	–2.43	na	–0.49
Coal, oil and gas	–0.22	0.27	–0.81	–2.78	–0.73
Minerals n.e.c.*	0.16	0.54	–	0.70	0.32
Services to mining	–0.04	0.62	–	–0.39	–0.09
Basic iron and steel	0.13	0.37	–	0.79	0.24
Non-ferrous metal products	2.84	–2.15	4.53	na	0.97
Residential construction	0.65	0.54	–	3.37	0.96
Other construction	2.41	0.63	–	12.20	2.65
Road transport	0.13	0.43	–	0.71	0.17
Rail transport	–0.07	0.38	–	–0.83	0.09
Finance (inc. software)	0.45	1.22	–	3.13	1.01
Electricity	0.17	0.51	–	1.20	0.44
INDUSTRY (65 SECTOR) INTERSTATE					
Ferrous metal ores	–0.12	–0.05	–0.17	–1.54	–0.50
Non-ferrous metal ores	–0.18	–0.01	–0.24	–2.36	–0.79
Coal, oil and gas	–0.12	–0.04	–0.25	–1.18	–0.38
Minerals n.e.c.*	0.07	0.32	–	0.70	0.16
Services to mining	–0.12	0.20	–	–0.74	–0.27
Basic iron and steel	0.11	0.24	–	0.82	0.19
Non-ferrous metal products	–0.08	0.01	0.09	–0.74	–0.26
Residential construction	0.24	0.35	–	1.31	0.34
Other construction	0.17	0.27	–	0.85	0.19
Road transport	–0.01	0.25	–	0.10	–0.02
Rail transport	–0.09	0.21	–	–0.36	–0.12
Finance (inc. software)	0.04	0.33	–	0.34	0.08
Electricity	0.02	0.25	–	0.26	0.05

Source: FEDERAL–SA projections.
**'not elsewhere classified'.*

O3 THE OPERATIONAL PHASE

In this and all subsequent scenarios national employment is constrained, that is, held constant. This is because it is conventional to assume that in the longer term the national economy will be close to full employment. This approach provides a lower-bound estimate of potential employment creation.

Operational phase: third scenario, 200,000 t/a capacity—national employment constrained

The Centre modelled the impacts of the operational phase by comparing direct cost estimates for the period 2000–01 to 2010–11, on an average annual basis, with those for 1996–97, which the Centre treated as a base-case year. WMC has provided detailed information on changes in the labour and operational costs and prospective returns for the Olympic Dam extension. The Centre has used these figures plus a judgment on capital costs, calculated annually as 6% of the total expenditure of the construction phase, to simulate the effects of the expansion. In the labour market, in this longer term setting, the Centre assumes that employment at the national level is constant. After discussing model results in this section, we turn to more detail on how model assumptions affect employment and electricity demand.

In this scenario, while only 191 jobs are created directly, the Centre projects that statewide employment increases by 0.17%, or 1,100 jobs. The jobs created are a combination of direct and indirect effects relating to production, plus spending effects arising from increased income. The response of employment growth to real GSP growth within the model is driven by model parameters. These have been calibrated using the historical linkage between GSP and employment in Western Australia during the mining boom in that state in the decade from 1985 (see 'Calibrating the linkage between GSP and employment' in Section O5).

Real consumption increases by 0.3% ($50 million) in South Australia and 0.1% in Australia ($163 million). Real investment in the respective regions increases by 0.6% and 0.1%. The balance of trade increases by $96 million. The income earned by capital increases (in nominal terms) by 0.7% in South Australia and 0.2% in the rest of Australia. Total nominal earnings of labour increase by 0.4% in South Australia and 0.3% in the rest of Australia. National CPI increases by 0.15%, with an increase of 0.2% in South Australia and 0.15% elsewhere (Table O.7).

Table O.7 Macroeconomic effects of Olympic Dam operational phase—national employment constrained

Expenditure side		% change from base case	Income side		% change from base case
Real GSP	– SA	0.37	Returns to capital (nom.)	– SA	0.72
	– rest of Aust.	0.06		– rest of Aust.	0.21
Real GDP	– national	0.08	Returns to labour (nom.)	– SA	0.44
GSP deflator	– SA	0.12		– rest of Aust.	0.26
	– rest of Aust.	0.17	Consumer price index	– SA	0.20
GDP deflator		0.16		– rest of Aust.	0.15
				– Australia	0.15
Real investment	– SA	0.58	Number employed	– SA	0.17
	– rest of Aust.	0.06		– rest of Aust.	–0.01
Real consumption	– SA	0.33		– Australia	0.00
	– rest of Aust.	0.07			
	– Australia	0.09			
Balance of trade (Australia) = +$96 million					

Source: FEDERAL–SA projections.

The projected impact on employment is an increase in South Australia of 0.2% or 1,100 jobs. As employment is constrained nationally, this is at the expense of interstate jobs. The end of this section includes an analysis of the sensitivity of employment estimates within this scenario to different closures.

The extent of the impact on South Australia's real GSP and Australia's real GDP of the operational phase depends critically on what the modeller assumes about the long-term capital costs. In an earlier study, the Centre did not account for capital costs associated with the construction phase (Wittwer and Bright 1996). Without including this cost, South Australia's real GSP increases by around 0.7% ($210 million) while Australia's real GDP increases by almost 0.2% ($650 million). We consider this to be an upper estimate of the gains from the project. In this study, we assume that the capital costs associated with the operational phase amount in annual terms to 6% of total construction costs. The gains from the operational phase are 0.4% ($115 million) to real GSP for South Australia and 0.1% ($340 million) nationally (Table O.7). For reasons that follow, we consider this a lower estimate of the gains from the project.

Turning to fiscal effects, higher company and personal tax revenue results in an annual decrease in the Commonwealth PSBR of $2 million. In part through increased royalties ($12 million) and increased payroll tax revenue ($3 million), the PSBR of the South Australian Government decreases by $19 million per annum, while that of interstate governments decreases by $10 million (Table O.8).

Table O.8 Fiscal effects of Olympic Dam operational phase—national employment constrained

	$M change from base case		$M change from base case
PSBR—SA ($m)	–19	SA payroll revenue—ores	0.1
PSBR—interstate ($m)	–10	SA payroll revenue—metals	0.3
PSBR—national ($m)	–2	SA payroll revenue—total	3.0
SA mining royalty revenues	12		

Source: FEDERAL–SA projections.

At the broad sectoral level, as in the construction scenarios, agriculture loses slightly due to the real exchange rate appreciation effect. But the direct output expansion in non-ferrous metal ores increases mining activity while that in non-ferrous metal products increases overall manufacturing activity. The direct impacts also induce increased activity in the services sector. Interstate, the real appreciation effect results in small losses in the export-oriented agricultural and mining sectors, with small increases in manufacturing and services induced by the spending effect of increased incomes (Table O.9).

Table O.9 Broad sectoral effects of Olympic Dam operational phase—national employment constrained

	South Australia % change from base case		Rest of Australia % change from base case	
	Output	Overseas exports	Output	Overseas exports
Agriculture	–0.26	–0.46	–0.26	–0.36
Mining	2.43	3.21	–0.55	–1.14
Manufacturing	0.64	1.94	0.19	1.31
Services	0.22	–	0.04	–

Source: FEDERAL–SA projections.

At the industry level, the category 'non-ferrous metal ores' experiences an increase in output of 14.5% with a corresponding increase in 'non-ferrous metal products' of 25.1% in South Australia (Table O.10). 'Coal, oil and gas' increases its output. This relies on the constant-cost assumption, without which output may change negligibly. That is, 'electricity' output increases by 4.5%, inducing increased demand for 'coal, oil and gas'. As WMC's demands are likely in part to be met by greater utilisation of existing electricity production within the national grid, including a steady demand for off-peak power, the increases in 'coal, oil and gas' and 'electricity' are probably exaggerated. We discuss this further under the heading 'The constant cost assumption and electricity demand'.

As stated above, there are increased demands resulting both from increased output of non-ferrous ores and metals, and from spending effects, reflected in the increase in aggregate real household consumption. These induce pervasive price increases with few exceptions outside the non-ferrous ores and metals industries. In some industries, notably 'electricity', these price effects may be model driven. In other industries where excess capacity is less apparent, they remind us that increased demands may increase scarcities that raise costs.

Table O.10 Industry level effects of Olympic Dam operational phase—national employment constrained

	Output	Producer price	Export volume (overseas)	Rate of return on capital	Employment
	% change from base case				
INDUSTRY (65 SECTOR) SA					
Ferrous metal ores	–0.55	0.21	–0.84	–0.54	–0.54
Non-ferrous metal ores	14.53	–9.73	22.33	3.06	3.01
Coal, oil and gas	1.40	0.20	–2.68	1.41	1.37
Minerals n.e.c.*	–0.07	0.22	–	–0.06	–0.07
Services to mining	0.87	0.21	–	0.90	0.84
Basic iron and steel	–0.03	0.06	–	0.00	–0.06
Non-ferrous metal products	25.14	–15.44	46.45	14.63	14.58
Residential construction	0.38	0.36	–	0.39	0.37
Other construction	0.34	0.40	–	0.39	0.39
Road transport	–0.04	0.21	–	0.02	–0.06
Rail transport	0.35	0.24	–	0.32	0.35
Finance (inc. software)	0.20	0.28	–	0.19	0.21
Electricity	4.52	0.22	–	4.52	4.51
INDUSTRY (65 SECTOR) INTERSTATE					
Ferrous metal ores	–0.58	0.13	–0.70	–0.56	–0.65
Non-ferrous metal ores	0.88	0.11	0.23	0.90	0.82
Coal, oil and gas	–1.50	0.14	–2.56	–1.48	–1.56
Minerals n.e.c.*	0.13	0.14	–	0.16	0.08
Services to mining	–0.16	0.14	–	–0.12	–0.21
Basic iron and steel	0.04	–0.03	–	0.10	0.00
Non-ferrous metal products	3.44	–0.33	7.78	3.48	3.37
Residential construction	0.08	0.15	–	0.13	0.05
Other construction	0.00	0.15	–	0.09	–0.01
Road transport	–0.02	0.20	–	0.04	–0.04
Rail transport	–0.65	0.17	–	–0.60	–0.67
Finance (inc. software)	0.04	0.18	–	0.07	0.00
Electricity	0.28	0.14	–	0.31	0.21

Source: FEDERAL–SA projections.
**'not elsewhere classified'.*

One result we should interpret with caution is that for 'non-ferrous metal products' interstate. The model assumes some substitutability between inputs from different regions. Sales of non-ferrous ores and metals from South Australia to interstate are non-zero within the model. So when further construction at Olympic Dam lowers the costs of production, interstate processors increase their purchases of South Australian non-ferrous ores and metals as their relative price falls. While in reality there may be some interstate sales, depicting these within the model may provide a misleading picture of the integrated processing plant at Olympic Dam. Therefore, as for 'electricity' in South Australia, we need to interpret cautiously the output shown for 'non-ferrous metal products' interstate.

Employment sensitivity analysis

It is common in CGE models to treat the employment rate as fixed, allowing wages to vary. However, in periods of high unemployment, it is logical to lift the employment constraint, allowing job numbers to vary. An approach taken in modelling the Olympic Dam expansion has been to keep national employment constrained, but to lift the constraint on employment in South Australia. The result is a predicted increase in job numbers in South Australia, for both the construction and operational phases of the expansion. Because the national increase in employment is set at zero, the increase in South Australia is at the expense of jobs in other states. We consider this a lower bound estimate of employment created.

If we lift the national constraint, the model projects that additional jobs will be created in Australia. The Centre has found that this appears to overestimate job creation, so the results are not reported here. An alternative is to increase national employment exogenously by a certain amount, and observe the distribution of jobs between South Australia and the rest of Australia. For example, if we assume that the operational phase provides 1,500 additional jobs at the national level, 1,120 of these jobs would arise in South Australia and 380 in the rest of Australia, a ratio of around 3 to 1.

Note that in Section O2, Scenario 2, although there is no constraint on labour at the national level, there is a constraint on industry capital stocks. This therefore should not result in an unrealistic magnification of job creation.

The constant cost assumption and electricity demand

Expansion to production of 200,000 t/a copper plus associated products would require an additional expenditure of $55 million per annum on electricity. WMC has indicated that additional electricity requirements are around 100 MW (representing the increase from 40–140 MW). We considered the potential impact on employment in Port Augusta, particularly through a possible increase in production from the Northern Power Station.

There does not appear to be scope for increased electricity requirements being met from the Northern Power Station. This is because the power station already operates at in excess of 80% of plant capacity. There is little scope for higher capacity utilisation, because use of brown coal at the plant results in more maintenance down-time than otherwise. Therefore, the impacts of the Olympic Dam expansion on activity in Port Augusta are likely to be negligible. On the other hand, if the ETSA Corporation (ETSA) chooses to upgrade the Northern Power Station, the impacts on the local region could be quite significant. But the Centre's discussions with ETSA indicate that this is not the most likely scenario.

There is scope for additional power to enter the grid from Penrice's cogeneration plant, located at Port Adelaide. The capacity of this plant is approximately equal to WMC's additional power requirements. There will also continue to be scope for buying power from interstate.

There are several reasons why the constant cost assumption of FEDERAL–SA will lead to underestimates of the gains from the project:

- The resource cost of WMC's additional electricity usage will be overstated by assuming constant costs. The project will require a steady load of electricity, thereby utilising offpeak supply to a considerable extent, reducing the resource cost. The additional electricity needs are approximately equal to the capacity of the cogeneration plant established at Port Adelaide. There appears to be little need for further new plants specifically to meet the additional electricity needs of the project.
- Given that Olympic Dam may expand further, and that a number of other mining developments are under way to the west of Roxby Downs, it is possible that WMC could lower its infrastructure costs by increasing its planned level of production or by entering into commercial deals to share infrastructure. Our fourth and fifth scenarios capture the benefits of constructing and operating a larger processing plant at Olympic Dam.

Should we overstate the resource costs of the project by assuming constant costs, we will also overstate the negative impact on other export-oriented industries through the real exchange rate effect. Hence, gains may be larger than our modelling indicates. On the other hand, historical evidence indicates that the proportion of national income earned by raw materials declines over time. Therefore, we might overstate the gains projected by our modelling arising from the operational phase as a proportion of total economic activity.

O4 SCENARIOS DEALING WITH POSSIBLE EXPANSION TO 350,000 t/a PROCESSING CAPACITY

A further option considered in this EIS is to expand the mining and processing capacity of Olympic Dam to 350,000 t/a of copper. As noted in Section O1, the WMC Board has made no formal decision to proceed with this further expansion at the present time. Investment of $900 million over two years and three months was modelled. The Centre, using a rule-of-thumb from within the industry, has applied scale economies to both the construction and operation phases. The formula used to calculate the costs of a larger scale project is as follows:

unit costs = (larger capacity/standard capacity)*n* × (standard capacity total costs)

where the exponent *n* equals 0.6 during the construction phase and 0.7 during the operational phase.

Some costs, such as maintenance, may increase proportionally to output. But we have insufficient information to apply anything other than the rule-of-thumb.

Construction phase: fourth scenario, 350,000 t/a capacity—national employment constrained

We assume in this scenario that construction of the possible expansion of Olympic Dam to 350,000 t/a copper begins during the operational phase of the 200,000 t/a project. The year that this is assumed to commence is approximately 2008. Hence, the results this time are compared with a 2006–07 operational phase base case. While the pattern of outcomes is similar to the 200,000 t/a construction phase, the actual percentage changes are slightly smaller. This is because the additional spending associated with the possible 350,000 t/a construction phase is smaller than for the 200,000 t/a construction phase.

Real GSP in South Australia increases by 0.3% ($87 million). The number employed in South Australia increases by 1,240 with labour constrained at the national level. Real consumption in South Australia increases by 0.1% ($15 million) and by approximately $50 million in Australia (Table O.11).

Table O.11 Macroeconomic effects of Olympic Dam construction phase—350,000 t/a capacity

Expenditure side		% change from base case	Income side		% change from base case
Real GSP	– SA	0.29	Returns to capital (nom.)	– SA	0.68
	– rest of Aust.	–0.03		– rest of Aust.	0.26
Real GDP	– national	0.00	Returns to labour (nom.)	– SA	0.53
				– rest of Aust.	0.33
GSP deflator	– SA	0.41			
	– rest of Aust.	0.29	Consumer price index	– SA	0.38
				– rest of Aust.	0.27
GDP deflator		0.30		– Australia	0.27
Private investment (real)	– SA	2.56	Number employed	– SA	0.19
	– rest of Aust.	0.42		– rest of Aust.	–0.01
Real consumption	– SA	0.09		– Australia	0.00
	– rest of Aust.	0.03			
	– Australia	0.03			

Balance of trade (Australia) = –$224 million

Source: FEDERAL–SA projections.

With increased imports of construction equipment and a larger squeeze on export industries, discussed below, the balance of trade worsens by around $224 million during the construction phase. The PSBR in South Australia decreases by $1 million. Again (as in the 200,000 t/a scenario), due to payments being indexed to CPI, the PSBRs of the Commonwealth ($65 million) and the other State governments ($16 million) increase.

As in the 200,000 t/a scenario, construction results in an increase in activity in services, notably in 'other construction' and 'road transport' in South Australia (Tables O.12 and O.13). But other sectors experience a small decline in output, while additional domestic demands impose a small reduction in exports.

Table O.12 Broad sectoral effects of Olympic Dam construction phase—350,000 t/a capacity

	South Australia % change from base case		Rest of Australia % change from base case	
	Output	Overseas exports	Output	Overseas exports
Agriculture	–0.28	–0.42	–0.20	–0.35
Mining	–0.18	–0.20	–0.15	–0.22
Manufacturing	–0.11	–0.88	–0.04	–0.54
Services	0.16	–	0.01	–

Source: FEDERAL–SA projections.

Table O.13 Industry level effects of Olympic Dam construction phase—350,000 t/a capacity

	Output	Producer price	Export volume (overseas)	Rate of return on capital	Employment
	% change from base case				
INDUSTRY (65 SECTOR) SA					
Ferrous metal ores	–0.11	0.04	–0.22	–1.61	–0.49
Non-ferrous metal ores	–0.31	0.06	–0.31	na	–0.95
Coal, oil and gas	–0.24	0.21	–0.70	–2.66	–0.78
Minerals n.e.c.*	0.11	0.46	–	0.63	0.22
Services to mining	–0.13	0.46	–	–0.82	–0.27
Basic iron and steel	0.06	0.32	–	0.55	0.11
Non-ferrous metal products	–0.35	0.18	–0.61	na	–0.67
Residential construction	0.05	0.35	–	0.39	0.14
Other construction	0.39	0.47	–	2.15	0.58
Road transport	1.80	0.57	–	9.28	1.97
Rail transport	0.04	0.38	–	0.45	0.05
Finance (inc. software)	–0.15	0.34	–	–0.95	–0.19
Electricity	0.26	0.88	–	1.83	0.58
INDUSTRY (65 SECTOR) INTERSTATE					
Ferrous metal ores	–0.14	–0.06	–0.18	–1.69	–0.57
Non-ferrous metal ores	–0.19	0.00	–0.21	–2.41	–0.76
Coal, oil and gas	–0.14	–0.05	–0.26	–1.33	–0.45
Minerals n.e.c.*	0.02	0.30	–	0.41	0.05
Services to mining	–0.16	0.21	–	–0.88	–0.34
Basic iron and steel	0.04	0.25	–	0.52	0.07
Non-ferrous metal products	–0.15	–0.02	–0.28	–1.31	–0.46
Residential construction	–0.01	0.22	–	0.03	–0.04
Electricity	0.00	0.32	–	0.15	0.01
Other construction	0.16	0.36	–	1.03	0.23
Road transport	0.10	0.3	–	0.67	0.11
Rail transport	–0.05	0.28	–	0.02	–0.07
Finance (inc. software)	–0.1	0.25	–	–0.36	–0.14

Source: FEDERAL–SA projections.
**'not elsewhere classified'.*

Operational phase: fifth scenario, 350,000 t/a capacity—national employment constrained

During the operational phase, real GSP in South Australia ends up 0.5% ($138 million) higher than otherwise (Table O.14). Employment in South Australia increases by 0.2%, or 1,190 workers. This is much greater than the direct employment impact of 510 jobs. The balance of trade improves by around $124 million. Total exports increase by about $220 million and total imports by about $100 million.The State governments experience a general increase in receipts. Payroll tax revenue increases slightly through higher labour income. South Australian mining royalties increase by $17 million (Table O.15).

Table O.14 Macroeconomic effects of Olympic Dam operational phase—350,000 t/a capacity

Expenditure side		% change from base case	Income side		% change from base case
Real GSP	– SA	0.46	Returns to capital (nom.)	– SA	1.13
	– rest of Aust.	0.08		– rest of Aust.	0.33
Real GDP	– national	0.11	Returns to labour (nom.)	– SA	0.58
				– rest of Aust.	0.38
GSP deflator	– SA	0.27			
	– rest of Aust.	0.25	Consumer price index	– SA	0.37
				– rest of Aust.	0.23
GDP deflator		0.25		– Australia	0.24
Private investment (real)	– SA	0.77	Number employed	– SA	0.18
	– rest of Aust.	0.08			
Real consumption	– SA	0.32		– rest of Aust.	–0.01
	– rest of Aust.	0.10		– Australia	0.00
	– Australia	0.12			

Balance of trade (Australia) = +$124 million

Source: FEDERAL–SA projections.

At the broad sectoral and industry levels (Table O.16 and Table O.17), services, manufacturing and mining increase by larger percentages than in the 200,000 t/a operational scenario in South Australia. The activity of service industries increases due to increased demands by 'non-ferrous metal ores' and 'non-ferrous metal products'. These two industries dominate changes in the output and exports of the mining and manufacturing sectors. And due to a larger cost squeeze, agriculture declines by a larger percentage.

Table O.15 Fiscal effects of Olympic Dam operational phase—350,000 t/a capacity

	$M change from base case		$M change from base case
PSBR—SA ($m)	–18	SA payroll revenue—ores	0.2
PSBR—interstate ($m)	–19	SA payroll revenue—metals	0.4
PSBR—national ($m)	8	SA payroll revenue—total	1.6
SA mining royalty revenues	17		

Source: FEDERAL–SA projections.

Table O.16 Broad sectoral effects of Olympic Dam operational phase—350,000 t/a capacity

	South Australia % change from base case		Rest of Australia % change from base case	
	Output	Overseas exports	Output	Overseas exports
Agriculture	–0.19	–0.73	–0.16	–0.54
Mining	2.16	7.22	–0.28	–1.72
Manufacturing	0.57	4.23	0.09	2.07
Services	0.16	–	0.03	–

Source: FEDERAL–SA projections.

Table O.17 Industry level effects of Olympic Dam operational phase—350,000 t/a capacity

	Output	Producer price	Export volume (overseas)	Rate of return on capital	Employment
	% change from base case				
INDUSTRY (65 SECTOR) SA					
Ferrous metal ores	–0.97	0.41	–1.45	–0.97	–0.97
Non-ferrous metal ores	25.22	–13.02	31.22	7.77	7.73
Coal, oil and gas	0.41	0.38	–4.20	0.42	0.40
Minerals n.e.c.*	–0.15	0.42	0.00	–0.17	–0.12
Services to mining	4.48	0.38	0.00	4.49	4.46
Basic iron and steel	–0.11	0.17	0.00	–0.08	–0.13
Non-ferrous metal products	35.23	–18.94	61.51	18.64	18.64
Residential construction	1.39	0.41	0.00	1.36	1.43
Other construction	0.27	0.78	0.00	0.24	0.28
Road transport	0.47	0.84	0.00	0.50	0.47
Rail transport	–0.12	0.37	0.00	–0.05	–0.14
Finance (inc. software)	0.36	0.43	0.00	0.26	0.40
Electricity	0.28	0.52	0.00	0.22	0.35
INDUSTRY (65 SECTOR) INTERSTATE					
Ferrous metal ores	–0.89	0.20	–1.08	–0.86	–0.99
Non-ferrous metal ores	1.30	0.18	0.30	1.33	1.22
Coal, oil and gas	–2.26	0.21	–3.90	–2.22	–2.34
Minerals n.e.c.*	0.22	0.22	0.00	0.27	0.15
Services to mining	–0.23	0.21	0.00	–0.18	–0.30
Basic iron and steel	0.07	–0.01	0.00	0.15	0.01
Non-ferrous metal products	5.20	–0.42	10.82	5.25	5.10
Electricity	0.34	0.21	0.00	0.39	0.25
Residential construction	0.11	0.23	0.00	0.18	0.08
Other construction	0.00	0.24	0.00	0.11	–0.02
Road transport	–0.02	0.30	0.00	0.06	–0.05
Rail transport	–0.96	0.26	0.00	–0.89	–0.99
Finance (inc. software)	0.06	0.27	0.00	0.10	0.01

Source: FEDERAL–SA projections.
*'not elsewhere classified'.

The impact of increased exports on the balance of trade

A further aspect considered is the impact on the balance of trade if all the additional output from Olympic Dam were exported. According to data provided to the Centre, direct output increases by $400 million in the possible 350,000 t/a scenario (above the 200,000 t/a base case).

The model assumes that virtually all the additional output is exported. Admittedly, as discussed in Section O3, some ores and metals are sold interstate within the model, and then are exported after further processing. The effect on the balance of trade is similar, whether through exports from South Australia or the rest of Australia.

With increased exports, there are also increased imports. These arise from spending effects stimulated by the mining project. Additional income could induce additional household consumption expenditures, or increased purchases of capital equipment by industry responding through increased investments.

In addition, through the real exchange rate appreciation effect of increased mining output, exports in other industries fall slightly. Therefore, the dollar improvement in exports from Olympic Dam will usually be several-fold higher than the dollar improvement in the balance of trade.

O5 AN OUTLINE OF FEDERAL–SA

What is FEDERAL–SA?

FEDERAL–SA is a model of the South Australian and Australian economies. It is in the ORANI family of computable general equilibrium (CGE) models. Such models have been used since the early 1980s to simulate the effects of policy changes, or other changes including events on world markets, on the Australian economy. FEDERAL–SA differs from the ORANI family in that it contains a lot of detail on two regions, South Australia and the rest of Australia. Within this detail, the model includes inter-regional linkages between South Australia and the rest of Australia. What this means is that a shock imposed on the interstate region of the model will have impacts on the South Australia region through the connections within the model. This is in addition to the intersectoral linkages that models of this type have.

An important part of models such as FEDERAL–SA is that they contain price competition for resources. This means that an increase in world demand for one commodity, or a technological increase in the industry producing it, will bolster the output and exports of that commodity. But other industries might lose out if they are export-oriented, because the initial impact induces a real exchange rate appreciation. An appreciation has the effect of lowering the domestic price received on world markets. So the good news in the industry with the initial benefit will be partly offset by bad news elsewhere. The overall gain to the economy therefore may be smaller than the initial benefit arising in that industry.

Because the models of this type include both consumers and producers, consumer activity will also be affected by the initial impact. It might be, for example, that the increase in world demand results in an increase in the industry's income. This in turn may mean increased taxation revenue. If the government distributes this to consumers, the increased spending arising from the initial impact will benefit some industries—and worsen the impact on others through a further increase in prices.

Given the array of possible impacts, in different directions and of different magnitudes, that the associated impacts might have on a particular industry, a simulation using a CGE model is necessary to establish the overall effect on that industry.

The theoretical structure of FEDERAL–SA

Being in the family of CGE models, FEDERAL–SA includes:

- substitution possibilities, between factors (i.e. labour, capital and, in agriculture, land) in production and commodities in consumption;
- changes in prices and quantities in a particular scenario, calculated within the model;
- the assumption of perfect competition, with exceptions, notably in imperfect substitution between sources by purchasing agents;
- utility-maximising consumers and profit-maximising producers;
- flexibility in the choice of which variables are endogenous, or calculated within the model, and which variables are exogenous, or held constant during simulations.

How CGE models differ from input–output models

As stated previously, CGE models include prices. Input–output models do not include prices and therefore do not capture the general equilibrium effects of price competition.

Prior to the availability of computing power to run full general equilibrium models based on microeconomic theory, input–output models had an important role to play in analysing economic impacts. The limitation of such models is that they lack resource constraints. That is, any increase in spending draws on additional labour and capital as though they are never scarce, although the modeller may impose additional costs as well as benefits on the model to depict net benefits in some circumstances. Frequently, at the regional or subregional level, the lack of constraints may not be an issue.

The use of different model settings or closures

The choice of endogenous and exogenous variables within FEDERAL–SA is flexible, as is explained above in the section dealing with generating solutions.

In short run simulations, we often assume that there is no constraint on labour, so that the employment level is free to vary, while real wages are fixed. In our first scenarios, we present two different assumptions about the labour market in order to check the sensitivity of results to our assumptions. What we do with the labour market at the regional level depends on what we are examining. In some long-run studies, interstate migration is of interest. So the unemployment rate is maintained at some constant level in both regions, and differences in regional outcomes result in interregional population flows—all the long-run scenarios in this paper assume this. Alternatively, the modeller could assume that wage differentials appear between regions, or could allow unemployment in the two regions to vary.

Capital stocks, on the other hand, are fixed in each industry in the short run, so that shocks will lead to variations in the rate of return on capital across industries. In the long run, we assume that industries have sufficient time to reallocate capital stocks to equalise rates of return on capital across all industries.

Indicators of welfare in CGE models

The Centre proposes that real GSP and GDP may provide better indicators of economic welfare effects than real consumption, which is sometimes proposed as the appropriate measure. The results for real GSP/GDP are less sensitive to the choice of closure than is consumption, as illustrated here for the operational phase of the 200,000 t/a scenario.

One test of the sensitivity of macroeconomic results is to vary the fiscal closure. When we constrain the PSBR, consistent with the notion that governments seek to balance budgets in the long run, the effect on real consumption increases. In South Australia, the increase is 0.40% ($60 million) with the PSBR constrained, while it is 0.07% interstate. This compares with 0.33% ($50 million) and 0.07% for the unconstrained case (Tables O.7 and O.18).

Table O.18 Distributing expenditure according to the closure used

Macroeconomic variable	South Australia	Rest of Australia	Australia
		% change from base case	
PSBR UNCONSTRAINED			
PSBR (G–T)/GSP	–0.02	–0.005 to +0.005	–0.005 to +0.005
Real consumption (C)	0.33	0.07	0.08
Real investment (I)	0.58	0.06	0.10
Balance of trade (X–M)/GDP			0.03
PSBR CONSTRAINED			
PSBR (G–T)/GSP	0	0	0
Real consumption (C)	0.40	0.07	0.09
Real investment (I)	0.65	0.06	0.10
Balance of trade as (X–M)/GDP			0.02

G–T: Government expenditure – taxation revenue; X–M: Exports – imports.
Source: FEDERAL–SA projections.

While real GDP nationally does not change between the two closures, real GSP increases by 0.41% with the budget constraint compared with 0.37% without in South Australia. The outcome for real consumption is therefore sensitive to the closure, as is to a lesser extent the effect on the State's real GSP, with little effect on national real GDP. The closure alters the distribution of gains between regions slightly, and between different expenditure types (i.e. the distribution of GDP between consumption, investment and the trade balance). For this reason, the Centre maintains that real GSP and real GDP may provide better indicators of welfare effects than real consumption. The sensitivity of real consumption to the closure increases as the revenue effects of a particular shock increase.

Calibrating the linkage between GSP and employment

Models such as FEDERAL–SA contain parameters for which estimates do not exist. In the case of parameters governing imperfect substitution by buyers between regions, for most commodities interstate trade data do not exist, let alone estimates of their responsiveness to changes in relative prices.

So, to calibrate these parameters, the Centre used the linkage between GSP and employment in Western Australia over the decade following 1985. In this time, there was a mining boom in that State. This largely explained a growth rate for GSP exceeding that nationally. This was accompanied by a population growth together with, following the recession of the early 1990s, a decrease in the unemployment rate relative to that nationally. The correspondence between GSP growth and employment (the latter a combination of reduced unemployment and increased population) for Western Australia is apparent in Figures O.1, O.2 and O.3. The Centre attributes this almost entirely to the mining boom in that State.

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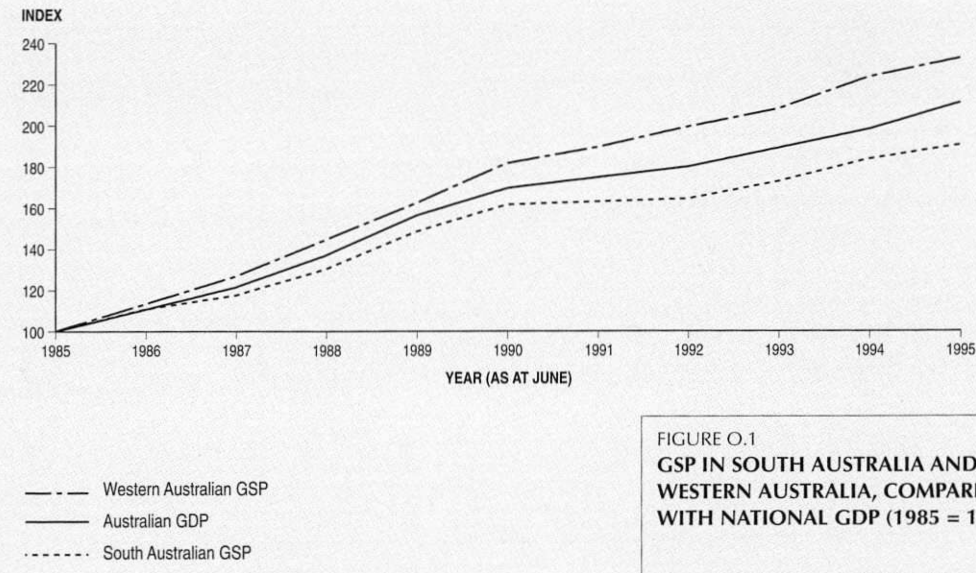

FIGURE O.1

GSP IN SOUTH AUSTRALIA AND WESTERN AUSTRALIA, COMPARED WITH NATIONAL GDP (1985 = 100)

Source: Australian Bureau of Statistics 1996a.

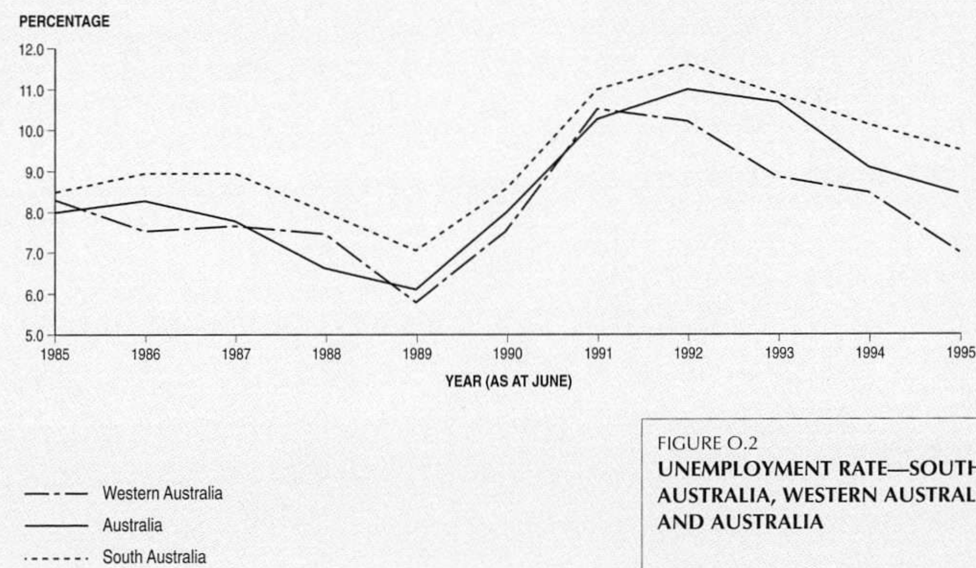

FIGURE O.2

UNEMPLOYMENT RATE—SOUTH AUSTRALIA, WESTERN AUSTRALIA AND AUSTRALIA

Source: Australian Bureau of Statistics 1996c.

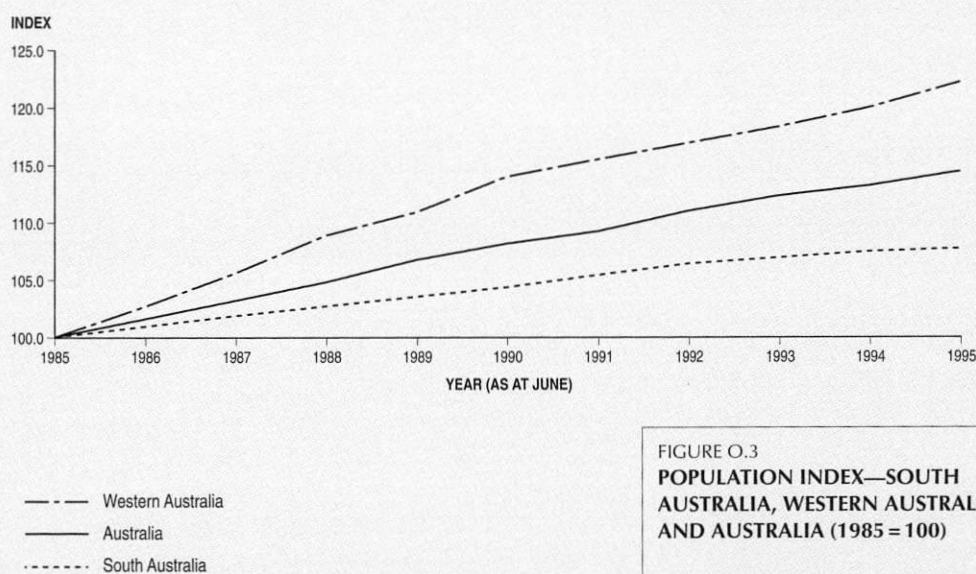

FIGURE O.3

POPULATION INDEX—SOUTH AUSTRALIA, WESTERN AUSTRALIA AND AUSTRALIA (1985 = 100)

Source: Australian Bureau of Statistics 1996b.

APPENDIX P

WORKPLACE HAZARDS AND CONTROLS

APPENDIX P

WORKPLACE HAZARDS AND CONTROLS

Workplace hazards particular to various parts of the Olympic Dam operations have been identified and are set out below. This hazard identification is a knowledge-based process, and the familiarity of operators with established plant has assisted compilation of this list.

P1 UNDERGROUND MATERIALS HANDLING, HOISTING AND SERVICES

Hazards	Control method
CHRONIC	
Noise	• Note standard more stringent since project start-up (90 dBA now reduced to 85 dBA). • Enclosed insulated cabins, personal hearing protection.
Silica dust	• Ventilation, enclosed filtered ventilation cabins, personal respiratory protection.
Diesel smoke etc.	• Ceramic filters, enclosed filtered ventilation cabins, personal respiratory protection. • Note indications of major 'tightening' of standard for submicron soot.
Dust (long-lived radionuclides)	• Ventilation, filtered ventilation cabins, personal respiratory protection (airstream helmet etc.).
Radon decay products	• Ventilation, filtered ventilation cabins, personal respiratory protection (airstream helmet etc.).
Chemicals sensitisation	• Choice of chemicals, procedures, personal protective equipment.
ACUTE	
Vehicle accident/impact	• One-way traffic, 'block' lights, backup alarms, rear-view cameras, procedures.
Rockfalls	• Routine back-bolting. • Regular checking.
Mechanical entanglement or impact	• Guarding, design for exclusion of personnel.
Electrical shock	• Enclosure, AS 3000 rules, ELCB on all 240 V AC outlets.
Fire	• Fuel bay: – elimination of ignition sources, AFFF system – ventilation to exhaust.
Heat stress	• Air-conditioned cabins, ventilation to maintain ACP greater than 150 W/m^2, 'spot' cooling when needed.
Trips/slips/falls	• From mobile equipment: – access/egress designs, non-slip treads. • From fixed plant: – handrails, steps etc.
Confined space entry	• Use of vessel entry procedures, tagout etc.
Blasting—accidents/explosive	• Low sensitivity detonators.
Blasting—fume exposures	• Ventilation, re-entry procedures.
Burns (thermal, chemical)	• Work practices and personal protective equipment.

P2 CONCENTRATOR

Hazards	Control method
CHRONIC	
Noise	• Grinding: – engineering controls to the extent practicable – personal protective equipment. • Flotation fans: – enclosure.
Dust (long-lived radionuclides)	• Washdown of slurry spillages to sumps.
Chemical sensitisation	• Automated mixing and personal protective equipment.
Radon	• Existing natural ventilation is adequate.
ACUTE	
Slip/fall hazards	• Walkways, good access, clean-up.
Vessel entry (tanks, mill maintenance, flotation cells etc.)	• Procedures, lockouts etc.
Electrical	• AS 3000 and enclosure, ELCB on all 240 V AC circuits.
Chemical fire	• At reagents area—fixed equipment.

P3 HYDROMETALLURGICAL AND SOLVENT EXTRACTION PLANTS

P3.1 Concentrate leach

Hazards	Control method
CHRONIC	
Skin sensitisation from slurry etc.	• Personal protective equipment.
ACUTE	
H_2SO_4, NaOH, corrosive, ore process reagents.	• Automated mixing and metering, physical containment.
NO_X, H_2S can be evolved, acid mist; NO_X has been ongoing problem (due to nitrous and nitric contamination in acid)	• Future nitrous and nitric contamination removal from sulphuric acid at acid plant.
Entrapment in pressure filter	• Lockout procedure.
Vessel entry	• Safe Work Permit for confined space work.
Manual handling during maintenance	• Monorails etc.

P3.2 Tailings leach, CCDs, and clarification

Hazards	Control method
ACUTE	
Sodium chlorate, H_2SO_4 corrosive, acid mist; has been release of HCl and NO_X	• Future nitrous and nitric contamination removal from sulphuric acid at acid plant.
Vessel entry	• Safe Work Permit for confined space work.
Manual handling during maintenance	• Crane access, monorails, lifting points.
High temperature, burns	• Personal protective equipment.
NaOH for wash of sand filters	• Personal protective equipment.

P3.3 Uranium and copper solvent exchange

Hazards	Control method
CHRONIC	
Chemical exposure—possible sensitisation (diluent, amine and oxime)	• Containment, personal protective equipment.
ACUTE	
Ammonia, weak and strong acid, NaOH, Shellsol, oxime, amine, skin contact, asphyxiation	• Containment, personal protective equipment.
Fire	• AFFF system.
Solvent vapour intoxication	• Ventilation in enclosed spaces.
Vessel entry	• Safe Work Permit for confined space work.

P4 AMMONIA AND DILUENT STORAGE, YELLOWCAKE PRECIPITATOR, CALCINATION

Hazards	Control method
CHRONIC	
Airborne U_3O_8 (chemical toxicity and radiation dose)	• Spillage control, ventilation, personal protective equipment.
Surface U_3O_8 (including skin and clothing)	• Shower and change facilities.
Noise (calciner building)	• Enclosure of venturi scrubber fans, personal hearing protection.
ACUTE	
U_3O_8 poisoning (kidney damage)	• Contamination control, personal protective equipment.
NH_3 corrosive	• Personal protective equipment.
Heat stress (top level calciner)	• Ventilation, shielding.
Fire (oil burner mishap etc.)	• Fire appliances, extinguishers.
Fire (diluent)	• Fire appliances, extinguishers.

P5 BACKFILL PLANT

Hazards	Control method
CHRONIC	
Lime exposure, slurry exposure (skin irritation)	• Personal protective equipment.
Noise (pumps)	• Engineering controls, personal protective equipment (ear protection).
ACUTE	
High-pressure fluid (release)	• Personal eye protection.
Lime contact with eyes	• Personal eye protection.
Vessel entry	• Safe Work Permit for confined space work.

P6 SMELTER

P6.1 General operations

Hazards	Control method
CHRONIC	
Concentrate dust (radiation dose by inhalation)	• Spot fume extraction and general building ventilation.
Smelter dust (radiation dose by inhalation)	• Spot fume extraction and general building ventilation.
^{210}Po fume (radiation dose by inhalation)	• Spot fume extraction and general building ventilation.
PAH from electric furnace (also ^{210}Po)	• Spot fume extraction and general building ventilation.
Noise	• Engineering controls to the extent practicable, personal protective equipment.
SO_2 (long-term hazard)	• Ventilation, personal protective equipment.
ACUTE	
SO_2	• Personal protective equipment.
Heat stress	• Cool refuges.
Smelter dust	• Enclosure, ventilation, personal protective equipment.
Burns (from hot metal/slag during tapping, hot equipment)	• Personal protective equipment.
High-pressure steam	• Engineering, personal eye protection.
Vessel entry	• Safe Work Permit for confined space work.
Entanglement in machinery	• Engineering, lockout procedures.
Fire	• Procedures, protection system.

P6.2 Specific plant areas (smelter)

Hazards	Control method
Feed preparation:	
• Dust	• Engineering, personal protective equipment.
• High-pressure steam	• Personal eye protection.
• Mechanical failures, entrapment	• Engineering, lockout procedures.
Oxygen plant:	
• Cold, N_2, high-pressure gases	• Procedures, engineering, personal eye protection.
• Fire	• Procedures, protection systems.
Flash furnace:	
• Hot metal, fumes, SO_2	• Engineering, ventilation extraction systems.
• Heat stress	• Ventilation extraction systems, cool refuges.
Anode furnace and casting wheel:	
• Noise	• Engineering controls, personal hearing protection.
• Heat stress	• Cool refuges.
Electric slag cleaning furnace:	
• Fumes, SO_2, CO, PAH	• Fume extraction systems.
Waste heat boiler:	
• Dust, vessel entry	• Personal protective equipment, Safe Work Permit.

P6.2 Specific plant areas (smelter) (continued)

Hazards	Control method
Electrostatic precipitator:	
• Dust, dust handling system	• Personal protective equipment, procedures.
• Equipment entry	• Lockout system, Safe Work Permit.
Boilers:	
• Chemicals	• Automatic dosing systems, personal protective equipment.
Acid plant:	
• SO_2, acid, vessel entry, sulphur fires	• Engineered containment, protective apparel, procedures.

P7 COPPER REFINERY AND GOLD ROOM

Hazards	Control method
CHRONIC	
Acid mist	• Improved cell design, enclosed cabins, reduced operator attendance, extraction ventilation.
Radionuclides in slimes	• Clean-up of spills.
Noise	• Engineering controls.
Fumes in gold room, NO_X, selenium, polonium, lead etc.	• Ventilation.
Arsenic in slimes (also cadmium and chromium)	• Clean-up of spills.
ACUTE	
Impact (crane, vehicle)	• Obstacle detection on crane.
Entanglement in machinery (cathode stripping etc.)	• Engineering, procedures.
Hot fluids	• Design for failsafe containment.
Acid contact, HNO_3 contact, fire	• Design for failsafe containment.
HCl and cyanide solution fire, silver cell electrolyte (strong oxidiser)	• Design to separate acid and cyanide, enclosure.
Arsine, Cl_2 gas in gold electrolysis, NO_X	• Ventilation.
Sodium cyanide, HCN gas (poisoning)	• Handling procedures.
Cyanide slimes	• Handling procedures, apparel.
Electricity	• Enclosure, AS 3000 rules, ELCB on all 240 V AC circuits.
Musculoskeletal (manual cathode stripping)	• Training, procedures.