Chapter 8
Physical Environment

This chapter describes the existing physical environment of the proposed sites and the potential impacts of the proposal on the physical environment. The physical environment includes:

- geology
- geomorphology
- soils
- surface hydrology
- hydrogeology
- climate
- air quality
- noise
- fire.

8.1 Geology

8.1.1 Regional Geology

The three proposed sites for the national radioactive waste repository are located in the Stuart Shelf geological province, to the west of Lake Torrens in South Australia. This province comprises incomplete sequences of flat-lying, undeformed Proterozoic (Precambrian) and early Palaeozoic (Cambrian) marine sediments of the Adelaide Geosyncline, overlying the northeastern part of the Archean Gawler Craton. The schematic geology of the area is shown in Figures 8.1 and 8.2.

The Stuart Shelf is bounded to the east and northeast by the Torrens Hinge Zone, a major northerly trending structural feature running beneath Lake Torrens and forming the boundary between the Stuart Shelf and the Adelaide Geosyncline. The northern extension of the shelf is overlain by sediments of the Jurassic/Cretaceous Eromanga Basin. A thin veneer of younger Cainozoic (Tertiary and Quaternary) sediments or in situ deposits (e.g. silcrete or calcrete) is commonly encountered at the landscape surface.

To the north of the Stuart Shelf the Eromanga Basin is the largest and most central of the three depressions that together make up the Great Artesian Basin (the other two are the Carpentaria Basin in northern Queensland and the Surat Basin in southeast Queensland and northeast New South Wales). Although the term ‘Great Artesian Basin’ has obvious hydrological connotations, it is entrenched in geological literature and has been used as a geological term even though the artesian and sedimentary limits are not the same. However, in this report the term Eromanga Basin is preferred, as there is no known or suspected hydraulic connection between the Great Artesian Basin aquifers, as important water resources, and the equivalent sediments in the study area.

The limit of Great Artesian Basin conditions and the limit of contiguous Eromanga Basin sediments in the study area are shown in Figure 8.1 (after Habermehl and Lau 1997).

The relationship between rock units, in stratigraphic order, is shown in Table 8.1. As detailed later, not all units are present at all three locations.

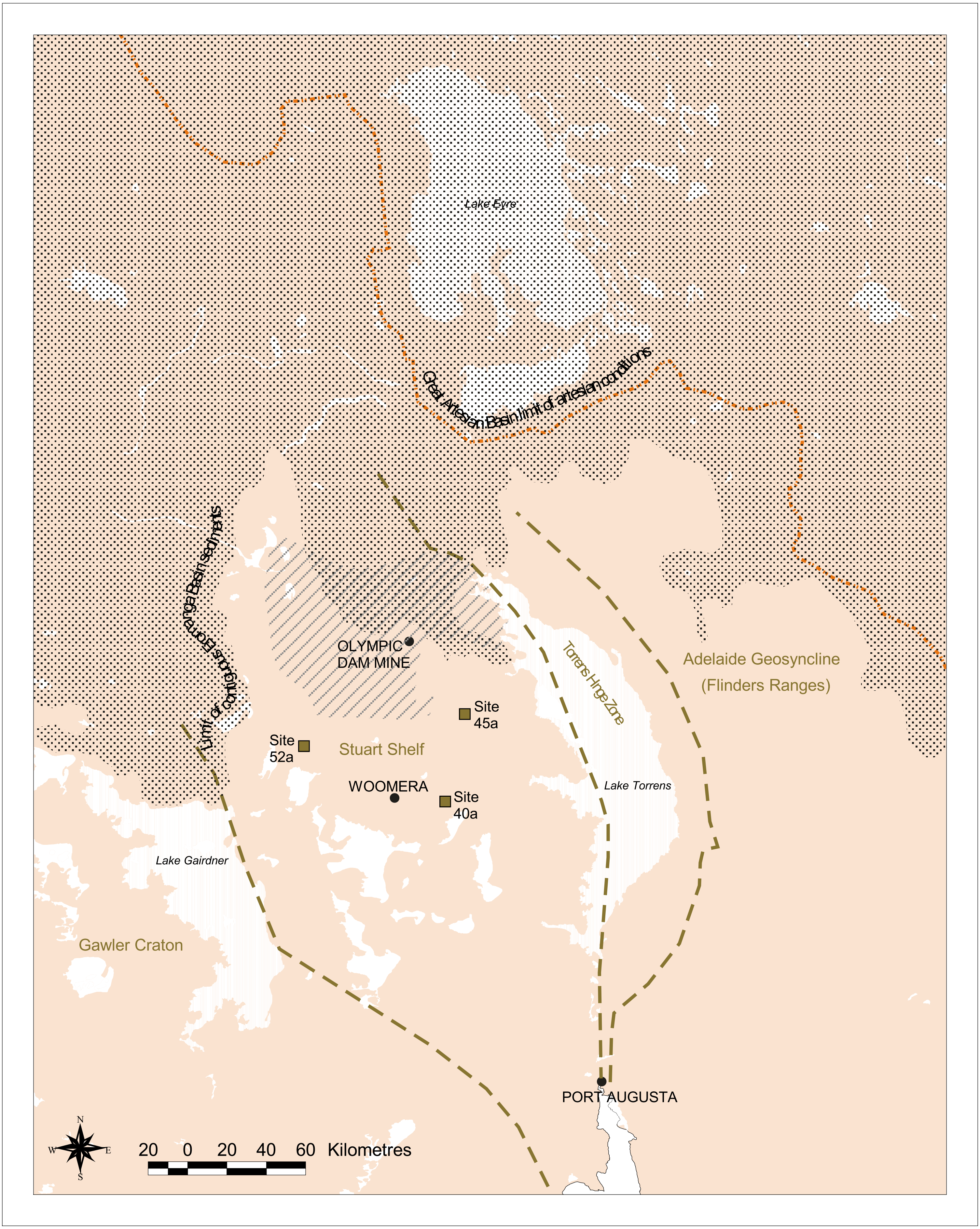
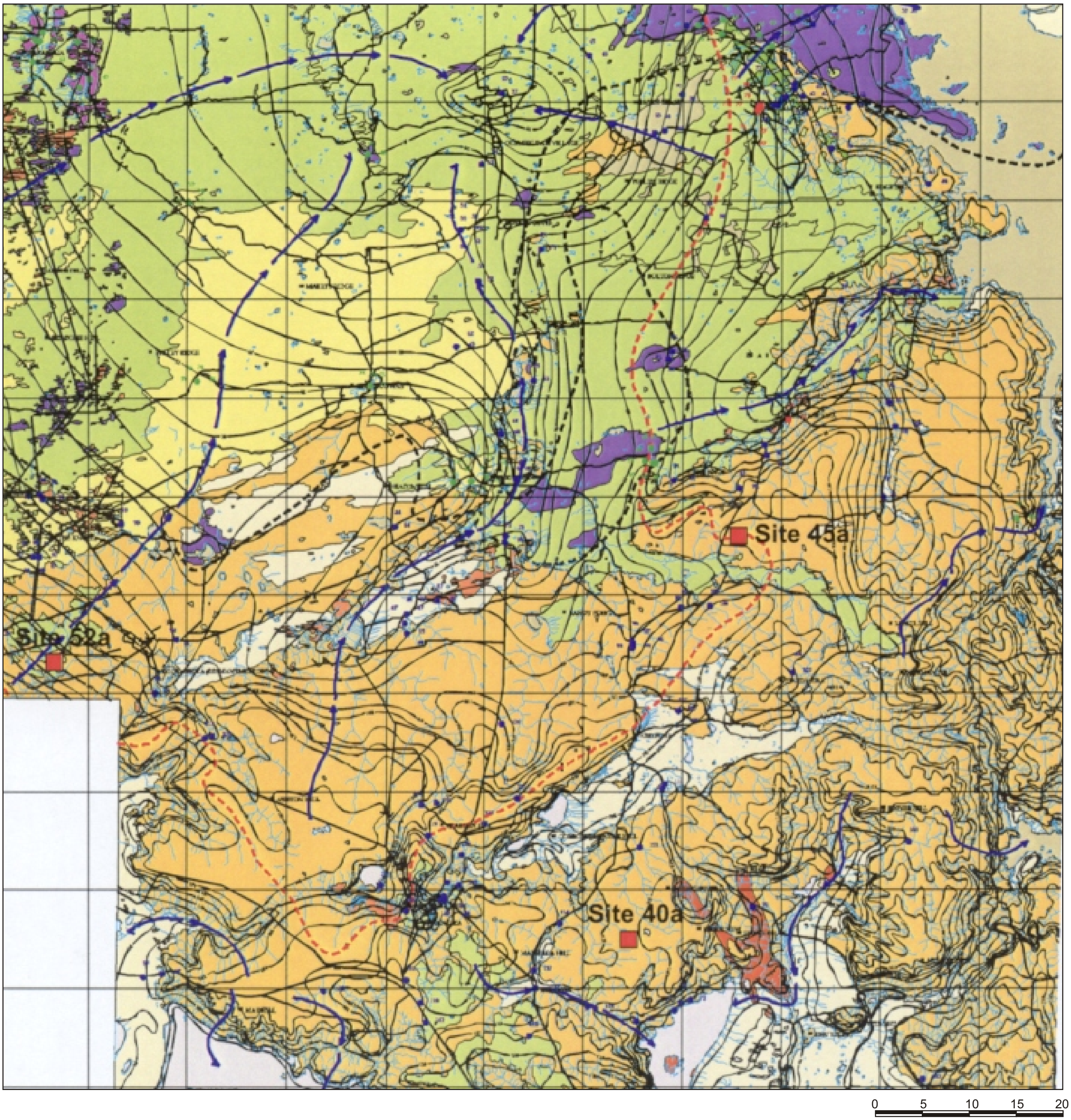


FIGURE 8.1

Schematic regional geology



Geology

🟫	**Qha**	Alluvium, of major drainage channels
🟨	**Qhs**	Sand plains
⬜	**Qhl**	Lakes: salt, gypsum, gypseous clays
🟨	**Qp**	Other deposits - Middle Pleistocene
🟧	**T**	Tertiary
🟩	**Kmb**	Bulldog Shale
🟩	**Kco**	Cadna-owie Formation
🟩	**Ja**	Algebuckina Sandstone
🟦	**CP**	Arckaringa Basin
🟪	**€a**	Andamooka Limestone
🟪	**€ac**	Curdlawindney Siltstone
🟪	**€y**	Yarrawurta Shale
🟧	**Ᵽw**	Wilpena Group
🟫	**Ᵽb**	Late Proterozoic; Umberatana & Burra Group
🟫	**Ᵽ**	Early to Mid Proterozoic
🟪	**qz**	Undifferentiated quartz veins/bodies
🟦	**fe**	Undifferentiated ironstone: ferruginisation
⬜		No data

Bores showing the height above sea-level to which water will rise

● 96	Bores within Kmb aquifer
● 108	Bores within Ja–Kco aquifer
● 78	Bores within €a aquifer
● 105	Bores within Ᵽ–Ᵽb–Ᵽw aquifer
	Limit of geology type
	Surface of drainage features
	Watertable contour
	Groundwater flowline
	Groundwater divide
	Lake Eyre drainage divide
	Roads
☒	Locality

Projection: Australian Map Grid, Zone 53

Geology derived form the Stuart Shelf Geoscientific GIS Dataset, Minerals & Energy, SA, 1998

Topographic and cultural features after the TOP02150k Dataset, AUSLIG, 1996

Produced by the Land & Water Science Division, BRS, 1999

FIGURE 8.2

Central–north South Australia

Geology and watertable contours

TABLE 8.1 Generalised stratigraphy of study area

Unit/Formation	Geological basin / group	Geological stage	Symbol	Alias: notes
Soil		Cainozoic/ Quaternary	Cz/Qc	Generally clay, often gypsiferous, some loamy soil also
Silcrete		Cainozoic/ Tertiary	Cz/Ts	Some calcrete and ferricrete also, formed in situ
Bulldog Shale	Eromanga Basin	Mesozoic (Cretaceous)	Kmb	Marine shale, upper parts may be moderately to highly weathered(1)
Cadna-owie Formation	Eromanga Basin	Mesozoic (Early Cretaceous)	Kco	Transitional non-marine to marine sediments(1)
Simmens Quartzite	Wilpena Group	Proterozoic (Marionan)	@ws	Arcoona Quartzite(2)
Corraberra Sandstone	Wilpena Group	Proterozoic (Marionan)	@wc	(2)
Woomera Shale	Wilpena Group	Proterozoic (Marionan)	@wm	Tregolana Shale(2)
Nuccaleena Formation	Wilpena Group	Proterozoic (Marionan)		Not encountered during drilling

(1) Krieg and Rogers 1995
(2) Preiss 1993

Note that at some site drillholes the two near-surface Cainozoic formations are distinct and are logged separately as Quaternary clay (Qc) and Tertiary silcrete (Ts), but if not distinct the more general Cz (Cainozoic formations) may be used.

Drilling during the Phase 3 program indicated that sediments underlying the three sites included sediments of the Wilpena Group (all sites) and the Eromanga Basin (Site 52a only).

The Wilpena Group is part of the youngest subdivision (Marinoan) of the Adelaidean succession and records two major transgressive–regressive cycles. Only the Lower Wilpena Group was encountered during the drilling program; the basal unit of the Wilpena Group, the Nuccaleena Formation, a micritic dolomite and interbedded shale unit, was not encountered. This is overlain by the 200 m thick Tent Hill Formation which comprises the Tregolana or Woomera Shale Member, which is overlain by the red beds of the Corraberra Sandstone Member (@wc) and the Simmens or Arcoona Quartzite Member (@ws).

Sediments of the Eromanga Basin extend into the study area (Figure 8.1). The southwestern third of the Eromanga Basin occurs in South Australia as a continuous blanket of sediments over the northeast of the state, where it laps onto older basement blocks and basins to the west and southwest. These sediments partly onlap and are partly in fault contact with elevated Adelaidean rocks including the Wilpena Group of the Stuart Shelf. The stratigraphy of the southwestern margin of the Eromanga Basin includes the non-marine Algebuckina Sandstone (Ja) which is overlain by the Cadna-owie Formation (Kco). Ja was not encountered in any of the investigative drilling programs.

Kco is typically 10–20 m thick around the basin margins and comprises non-marine to marine siltstones and fine-grained sandstones with some coarse-grained sandstones and carbonaceous claystone intervals. Kco is overlain by marine mudstones of Kmb, which has a maximum thickness of approximately 340 m but thins stratigraphically and by erosional stripping toward the southwest. Thicknesses of less than 200 m have been recorded in the Oodnadatta and Marree regions, with outlying remnants recorded in the Andamooka and Woomera areas (not all of which are mapped).

8.1.2 Geology of Sites 40a, 45a and 52a

Stage 3 Assessment Methodology

Following assessment of technical results of Stage 2 drilling of five investigated sites for the national repository (Bureau of Rural Sciences 2001a), and taking into consideration comments received during stakeholder consultation, three sites were selected for further investigation in Stage 3 — Sites 40a, 45a and 52a (Bureau of Rural Sciences 2001b).

In Stage 3 four holes were drilled at an in-fill 750 m spacing around the 1.5 km perimeter and a further eight holes were drilled at a 250 m spacing about an inner 500 m square (Figure 8.3). A total of sixteen holes were drilled at each of the three sites, including two diamond core holes at each site in the Stage 2 drilling, with the remainder by reverse-circulation air-hammer drilling.

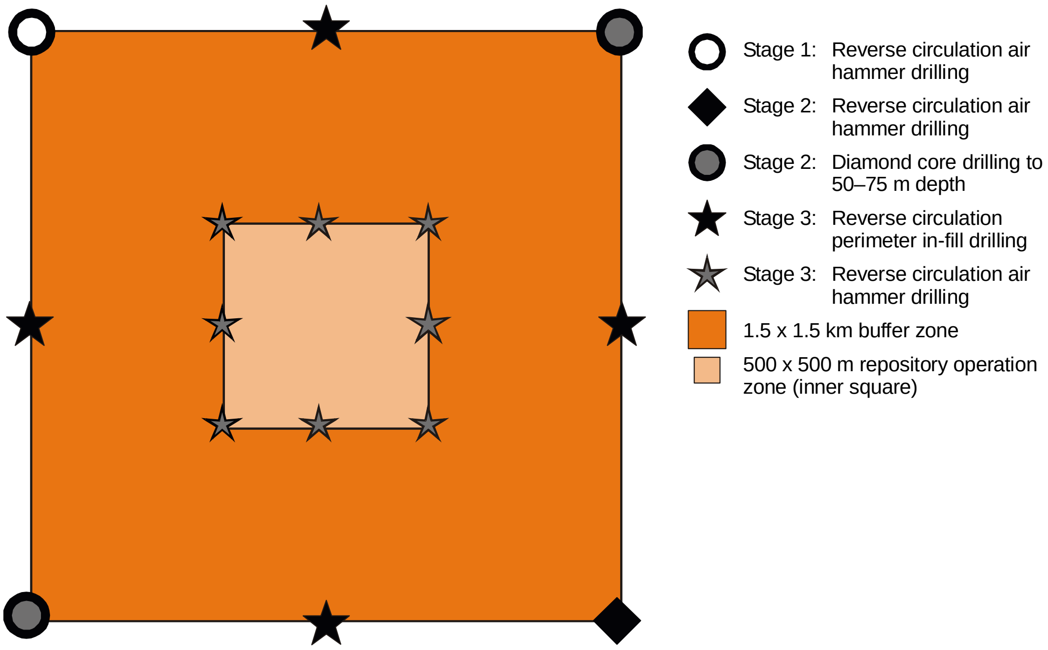


FIGURE 8.3
Drillhole locations

Sampling from the reverse-circulation drilling was done every metre from surface to target depth in the range 70–100 m. The lithology of samples obtained from all percussion holes was described (Bureau of Rural Sciences 2001a, b). Samples were split on site into two large subsamples — one for analytical purposes and the other to be stored in the Department of Defence Hangar B at Woomera. From the residue, material was wet-sieved and then placed into plastic sample trays. Both the percussion hole subsamples and diamond cores were available for inspection at the Bureau of Rural Sciences Land and Water Sciences Division laboratory, Symonston, Canberra.

In addition, the elevation of each drillhole was surveyed. Together these data were used to produce detailed (0.5 m) topographic as well as subsurface (structure) and thickness (isopach) contours of the geological formations. The contours provide an excellent basis for interpreting the three-dimensional configuration of each site. Further details are given in Bureau of Rural Sciences (2001b). Summary figures by the Bureau of Rural Sciences showing topography, watertable levels and stratigraphy are given in Appendix C1.

Site-Specific Geology

Table 8.2 summarises the geology encountered at each site, compiled from Bureau of Rural Sciences (2001b) data. Note that the silcrete layer is discontinuous and may be thinner or partial at some locations within each site.

TABLE 8.2 Summary of geology encountered during Phase 3 assessment

Site 40a		Site 45a		Site 52a	
Max. depth of formation (range)	**Lithology**	**Max. depth of formation (range)**	**Lithology**	**Max. depth of formation (range)**	**Lithology**
2–3.5 m	Clay	2–3 m	Clay	1–3 m	Clay
4–8 m (where present)	Silcrete	4–7 m	Silcrete	2–8 m (where present)	Silcrete
24–44 m	Simmens Quartzite	18–36 m	Simmens Quartzite	13–27 m	Bulldog Shale
69–79 m	Corraberra Sandstone	70+–100+ m	Corraberra Sandstone	38–45 m	Cadna-owie Formation
75+–90+ m	Woomera Shale			65–82 m	Corraberra Sandstone
				70+–100+ m	Woomera Shale

Source: Bureau of Rural Sciences 2001b

The surface clays at each site are generally reddish brown, of medium plasticity, sometimes gypsiferous, becoming more plastic with depth, and with minor calcrete nodules at the base. Tertiary silcrete is also common across the three sites — silcrete at Site 45a occurs as hard bands, whereas massive hard to very hard silcrete is present at Site 40a. The silcrete is generally ferruginised at the top and contains quartzite cobbles in many places. Softer, fractured silcrete and calcrete were observed at Site 52a.

Weathering in @ws is highly variable and the degree of weathering changes across Sites 40a and 45a. Where deeply weathered, it has changed (in bands) to white kaolinitic clay and pale greenish grey clays of low to medium plasticity. Generally, the top half to two-thirds of the clay bands in @ws are gypsiferous.

@ws has been interpreted by the Bureau of Rural Sciences to be a diagenetic weathering surface of @wc, and is not present at Site 52a. The boundary between @ws and @wc is designated primarily on hardness and on lithology (a change to maroon, generally fissile, silicified sandstone with siltstone interbeds typical of the @wc red beds).

Bulldog Shale (Kmb) intersected at Site 52a is a sequence of white massive mudstone and siltstone, grading to pale yellowish brown or grey mudstone at depth. The top is salinised and kaolinised by prolonged and intense weathering (bleaching), and is also highly gypsiferous and ferruginised in the upper part of the section. X-ray diffraction identified amorphous, opaline silica, but there has been no trace of macroscopic opaline material to suggest gem quality or economic worth in material from the diamond cores and percussion chips.

The lower part of Kmb contains well-rounded cobbles and boulders of quartzite. It conformably overlies weakly indurated lithic and quartzose sandstones of Kco, a coarsening-upward sequence from clayey fine sands at the base to fine to medium sands at the top. Bands containing loose sand were encountered at the top of Kco in about half of the holes drilled at Site 52a.

The total thickness of the Mesozoic sequence (Kmb and Kco combined) varies between 35 and 45 m. The Mesozoic sediments at Site 52a are interpreted to represent an isolated outlier of the western Eromanga Basin, based on the presence of outcropping and subcropping Proterozoic rocks within a few kilometres of the buffer zone. Bands of dry, weakly indurated to unconsolidated fine sands occur at the top of Kco and, to a lesser extent, near the base of Kmb. Typically, the bands are a few centimetres thick but individual beds range up to 30 cm in the southwest part of Site 52a.

Geological Host Rock

Table 8.3 summarises the geological host rock at each site, based on the results of the Phase 3 assessment and the proposed repository design, which indicates a trench depth of 15 m (Section 6.2.3).

TABLE 8.3 Geological host rock at each site

Site	Geology encountered by 15 m deep trench
Site 40a	Tertiary clays and silcrete with @ws at base
Site 45a	Tertiary clays and silcrete with @ws at base
Site 52a	Tertiary clays and silcrete with Kmb at base (and Kco at base in northeastern corner of operation zone, if that area is trenched).

Based on Bureau of Rural Sciences (2001b)

8.1.3 Seismicity

The level of seismic activity in Australia is generally considered to be low when compared to the seismically active areas of the world.

The most seismically active areas of South Australia are associated with the Adelaide Geosyncline in an area extending from the Flinders Ranges in the north to Kangaroo Island in the south; the eastern portion of Eyre Peninsula; and the southeastern region of the state around Mt Gambier.

The area between Quorn and Leigh Creek has the highest number of seismic events (considered to be related to zones of crustal weakness), with several earthquakes ranging in magnitude from Richter Local Magnitude (M_L) 4.5 to 5.7 between 1939 and 1983. Activity west of the Torrens Hinge Zone, in the areas of the proposed repository, range from M_L 1 to 2 (with M_L 2 being the lowest magnitude able to be felt). Discussion with the South Australian Office of Minerals and Energy Resources has indicated that the cluster of predominantly M_L 1 recordings are likely to be related to blasting activities associated with mining at Olympic Dam and Mt Gunson.

In Eyre Peninsula the earthquakes appear to be associated with the Lincoln Fault Zone, the highest recording being the 1959 Mambin earthquake of magnitude M_L 4.9. In the South East, seismicity is related to the western margin of the Otway Basin and an onshore volcanic belt. The highest recorded earthquakes are the 1897 Beachport–Kingston earthquake of magnitude M_L 6.5 and the 1948 Robe earthquake of magnitude M_L 5.6.

The Standards Association of Australia AS 1170.4-1993, Minimum Design Loads on Structures, Part 4 Earthquake Loads indicates that a ground acceleration coefficient of 0.08 would be appropriate for Site 52a, and between 0.085 and 0.09 for the eastern sites. There is a 10% probability that the aboveground acceleration levels would be exceeded in a 50-year period.

The repository and buildings would be designed in accordance with AS 1170.4-1993.

8.2 Geomorphology

All three sites are located within the central clay pan and plateau landform and soil region as defined by Laut et al. (1977). This region includes a variety of landforms between Lake Torrens and the Great Victoria Desert. Sites 52a and 40a are located within the Woomera environmental association and are characterised by moderately deep, well-drained red duplex soils. Site 45a is located within the Andamooka environmental association (a gibber covered plateau with shallow well-drained loams).

All three sites lie at elevations of 120–200 m above sea level on broad, elevated gibber plains with clearly defined water drainage courses which eventually fall 60–100 m in height to larger regional drainage systems. Gibber stones vary in composition, size and angularity across and between sites. Gibber at Site 40a is mainly resilicified sandstone, ranging from small cobble to boulder size, with most having a slabby form. At Site 45a the gibber has a similar composition but is typically smaller, with most being large gravel to large cobble size and having a mainly flaggy form. Site 52a is distinctly different, having nodular silcrete and shale flakes smaller than cobble size.

Site 40a is approximately 189 m above sea level at its centre, with a maximum relief of 4 m over the 0.5 km inner square. The surface and drainage features at Site 40a show the greatest variety of the three sites, with a slightly elevated ridge trending approximately north–south, a canegrass swamp on the northeastern boundary, and a subtle drainage depression which drains away from the western margin. There is a small area of water catchment upslope from the site, from which sustained, heavy rainfall could produce run-on to the site.

Site 45a is approximately 131 m above sea level at its centre and has a maximum relief of 8 m over 1.5 km. The surface features define a clear, broad drainage path running from the southeast to the northwest. Of the three sites, Site 45a has the largest upslope catchment area for rainwater run-on, and there is a clear drainage path which conducts runoff from the site. The old Arcoona to Andamooka road crosses the outer northwestern corner, and this concentrates localised rainfall before it joins the larger drainage path.

Site 52a is approximately 158 m above sea level at its centre and has surface features which are the least distinct regarding a surface drainage path. The site has a gentle slope to the east (12 m over 1.5 km) and the smallest catchment area for rainwater run-on. A gravel road lies along the northern edge of the site.

8.3 Soils

Harries et al. (1998) were commissioned to conduct a desk study on vadose zone hydrology and radionuclide retardation in the central–north region of South Australia, which had been proposed as a potential site for the national low-level radioactive waste repository. This report found that the soils and landscapes of the region are well described in the literature; however, the hydraulic and other physical characteristics of the soils are poorly known. In general, the soil hydraulic behaviour was inferred from experience elsewhere.

Three major soil groups were identified within the region. Following the nomenclature in *Handbook of Australian Soils* (Stace et al. 1968), the following soil groups were identified:

- grey brown and red calcareous soils [Map Code 7]
- desert loams [Map Code 8]
- solonised brown soils [Map Code 19].

The soils are old and deeply weathered, and tend to be sodic at the surface with accumulations of calcrete at depth. The surface sodicity results in structural instability during rainfall, which substantially restricts infiltration. The soils range from uniform profiles to gradational ones of medium texture. The desert loams tend to have texture contrast features with sandy loam overlying medium clay. There are significant areas of soil with relatively high amounts of smectite relative to kaolinite. This results, even in this environment, in shrink/swell behaviour and areas of gilgai (the microrelief of the soils, showing localised small depressions). It is not possible to avoid such areas in site selection as the gilgai feature is ubiquitous in this landscape.

In 1998 the Australian Nuclear Science and Technology Organisation (ANSTO) and CSIRO used remote sensing data (enhanced Landsat TM images) to determine the distribution of these soils based on soil surface texture image information. The images suggest that the Woomera–Koolymilka region has quite extensive and relatively uniform areas of similar soils; however, they possibly do not differentiate between soil types. The Woomera–Koolymilka sheet area stretches north and west of Woomera and Pimba, and is bounded in the south by a scarp which borders the large salt Lakes Gairdner, Hart and Island Lagoon. The landscapes north of this scarp are characterised by soils with clay and oxides of iron in the surface. The ‘plateau’ surface drains sharply to the south and more gently to the north.

Approximately 50 km north of Woomera this surface gives way to soils characterised by broadly spaced, linear, wind deposited sand dunes; low, broadly spaced rolling stony rises; and some small salinas. Soils here are characterised by hardpans, silcrete and calcrete in swales. Some detail on these landscapes is provided by Graetz and Tongway (1980). None of the three candidate sites are located in sand dunes.

Soil surfaces throughout tend to be sodic and structurally unstable. In the south, surfaces are protected by stones (gibbers). The ‘dune country’ is subject to significant sheet erosion by both water and wind. Milnes and Wright (1993) describe features of the landscape. Thickness of the soils and subsoils is around 2 m on the plateau west and northwest of Woomera, gradually increasing to about 5 m toward the ‘dune country’. Preliminary landform data from remotely sensed information suggest that these soils overlie saprolite of unknown thickness which grades into the Arcoona Quartzite. The ‘saprolite’ overlying the quartzite may consist of several metres of silcrete or calcrete immediately beneath the surface soil profile.

Australian Nuclear Science and Technology Organisation and CSIRO (1999) collected soil samples from two sites near Pimba (not from the study areas) inferred to be ‘characteristic’ of the site areas. The samples were collected from a range of depths, some from 1.3–1.5 m, some from auger samples of disturbed soil, and some from small undisturbed cores and large cores. They were packed in polythene bags to prevent water loss in transit to the laboratory. Testing of these samples was conducted to confirm the general intuitions about soils of the area as well as to provide a preliminary ‘order of magnitude’ check on the calculations made by Australian Nuclear Science and Technology Organisation and CSIRO (1998). The samples collected were tested for:

- water content
- bulk density
- hydraulic conductivity
- soil moisture characteristics
- particle size
- coefficient of linear shrinkage
- structural stability
- soil water chemistry
- radionuclide absorption.

The results of the above soil tests indicated the following:

- The pH is consistent with mild sodicity.
- The specific conductivity of the soils indicate saline conditions.
- The soils are ‘whole coloured’ red (desert loams).
- The field texture is consistent with desert loams.
- Emerson dispersion tests showed that all remoulded samples were stable although some near-surface natural samples showed some dispersion. This was attributed to the presence of gypsum nodules, which do not affect the natural aggregate test because of

their low solubility, but which are distributed through the soil during remoulding and confer stability on the remoulded samples.

- Throughout each profile, soil water contents at the time of sampling were somewhat drier than the wilting point water content.
- The soils contain a high fraction of material in the silt to very fine sand range. Particle size analysis indicated that clay content is low; however, this may be due to inadequate dispersion because of the presence of significant amounts of gypsum and calcium carbonate ($CaCO_3$).
- The soils swell with increasing water content but the cation exchange capacity is low due to the relatively modest clay content.
- Saturated hydraulic conductivity for the soils was measured as 0.06–0.20 cm/h, with the subsoil conductivity slightly less than at the surface.
- The surface soil structure and subsoil structure appear to be stable.
- Shrinkage tests indicated that the soils are quite reactive. Profiles are strongly pedal but do not show strong shear surfaces characteristic of shrink/swell soils.

8.4 Surface Hydrology

There is no permanent surface water in the study area. Ephemeral streams are common, but contain water on an infrequent basis. The description given by Kotwicki (1986) for the nearby Eyre Basin may be applied to the study area also. All streams are characterised by extreme variation in discharge and flow. Very variable seasonal and annual runoff are caused by occasional heavy rainfall (often caused by summer incursions of tropical low-pressure systems) and extended periods of drought.

Surface water drainage, when it occurs, is internal to salt lakes. Named salt lakes in the study area include Lake Torrens in the east, which is over 150 km long, Island Lagoon south of Pimba, and Lakes Windabout and Hart south of Sites 40a and 52a, respectively. However, Sites 40a and 52a fall outside the immediate surface water catchments of these major lakes. Site 40a drains east or north towards an indefinite terminus, while Site 52a drains towards a minor salt lake, Koolymilka Lake. Site 45a appears to drain towards Lake Torrens.

The surface landforms at the three sites indicate that each would shed heavy and sustained rainfall rather than holding water to cause surface flooding. In an extremely heavy and/or sustained rainfall scenario, run-on and runoff would be shed to adjacent drainage lines and very much lower lying areas faster than water can accumulate at any of the sites. The topography of the sites is shown in Appendix C1.

8.4.1 Site 52a

Although close to Lakes Hanson and Hart to the south, Site 52a is north of the surface water divide and drains eventually to the north into Koolymilka Lake near the former township of Koolymilka.

Site 52a has little headward catchment for rainfall to run-on to the site. Gilgai depressions and ‘crabholes’ in calcretes tend to cause minor short-term puddling on-site following rain. The site slopes from the west to the east with a total relief of 12 m over 1.5 km. A small ephemeral stream ‘Wild Dog Creek’ occurs approximately 800 m southeast of the outer square of investigation bores at this site (approximately 1250 m from the inner square).

8.4.2 Site 40a

Although close to Windabout Lake to the southeast, surface drainage at Site 40a is to the northeast towards an area of ill-defined drainage without major salt lakes.

Site 40a contains the greatest surface form diversity. There is a large canegrass swamp on its eastern edge and a subtle surface depression which leads west to the head of Rocky Creek. Overall, the site slopes to the west by 3 m over 1 km although the inner square slopes by 4 m over 0.5 km. A small ephemeral stream 'Bluff Watercourse' occurs approximately 1100 m northeast of the outer square of investigation bores at this site (approximately 1300 m from the inner square).

8.4.3 Site 45a

Site 45a is located close to but apparently immediately east of the surface water divide between the catchment of Lake Torrens to the east and an area of ill-defined drainage without major salt lakes to the southwest.

Site 45a slopes from the south to the northwest with a total relief of 8 m over 1.5 km. There is a small run-on catchment area to the east but there is a clear movement path across the site to shed water. Surface water eventually drains to Lake Torrens.

8.5 Hydrogeology

8.5.1 Broad Regional Hydrogeology

Habermehl and Lau (1997) show the hydraulic extent of the Great Artesian Basin finishing immediately south of Lake Eyre, some 100 km north of the study area. Eromanga Basin sediments are absent from two of the three sites examined here and, where present at Site 52a, are interpreted to be near the southwestern extreme of the Eromanga Basin. These features, as they occur in the study area, are shown in Figure 8.1. Hydrogeologically, the Eromanga Basin sediments, where present in the study area, are part of the Stuart Shelf aquifer system.

A comprehensive regional hydrogeological assessment of the project area and surrounds is provided by Kellett et al. (1999). The report documents a reconnaissance survey of the hydrogeology of an area covering 38,000 km^2 in central–north South Australia. The region has been identified as the preferred site for the national repository, and includes the three sites covered by this draft environmental impact statement (Draft EIS). The specific aims of the study were to:

- determine the location, extent and interrelationship of the significant hydrogeological units in the region
- assess the hydraulic properties of the different units contributing to flow
- estimate average groundwater flow rates, residence times and prevailing directions of groundwater flow
- identify recharge and discharge zones
- determine depths of watertables and estimate their seasonal fluctuations.

Figure 8.4 shows the general hydrogeological relationships in the region in cross-section (but not the Kco–Ja aquifer as it is off-section).

The dominant aquifers in the central part of the study area are sandstones of the Permo-Carboniferous Boorthanna Formation (CPb) and the Cambrian Andamooka Limestone (#a). These two aquifers receive discharge from Kco–Ja and transmit groundwaters to the two major regional sinks — Lake Torrens and the Olympic Dam mine (dewatering of the mine has created a regional groundwater sink — see watertable contours in Figure 8.2). Travel times through Ca may exceed 100,000 years. Total residence times between infiltration at ground surface and ultimate discharge reach up to 200,000 years for the northwest–southeast flowlines. The Ca is not present at Sites 52a, 40a and 45a but occurs further to the north, northeast and northwest. Areas underlain by #a were specifically excluded during the site selection process because of the karstic nature of the limestone.

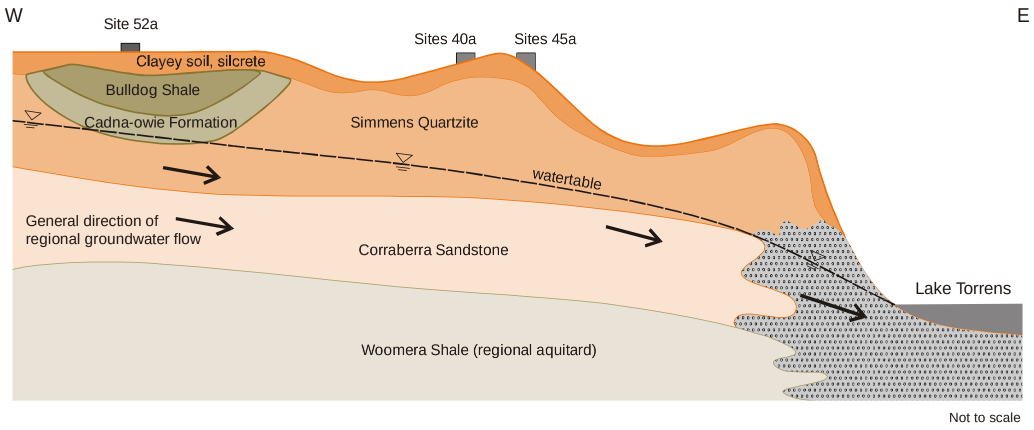


FIGURE 8.4
Generalised schematic hydrogeological section

The Late Proterozoic Simmens (Arcoona) Quartzite–Corraberra Sandstone (@ws–@wc) comprise the fractured rock aquifer of the Andamooka Ranges and Arcoona Plateau of the eastern part of the study area (which incorporates Sites 52a, 40a and 45a). Flow systems in @ws–@wc are localised with flowlines generally shorter than 20 km. Discharge is to the abundant salt lakes of the region and lateral flow velocities vary between 2 and 4 m/yr. Typical residence times between infiltration and discharge in the Proterozoic fractured rocks are from 10,000 to 20,000 years. Groundwater flow directions are shown in Figure 8.4. Note that the regional flowlines on the figure are illustrative and do not represent individual underground ‘streams’.

Depth to watertable exceeds 100 m in some parts of the northwest, and 50 m in most of the northern half of the study area and over much of the Andamooka Ranges and Arcoona Plateau (Figure 8.5). The shallowest watertables occur in the southwest, south and east, where they generally lie within 30 m of ground surface. Watertables lie within 5 m of ground surface in the vicinity of the salt lakes.

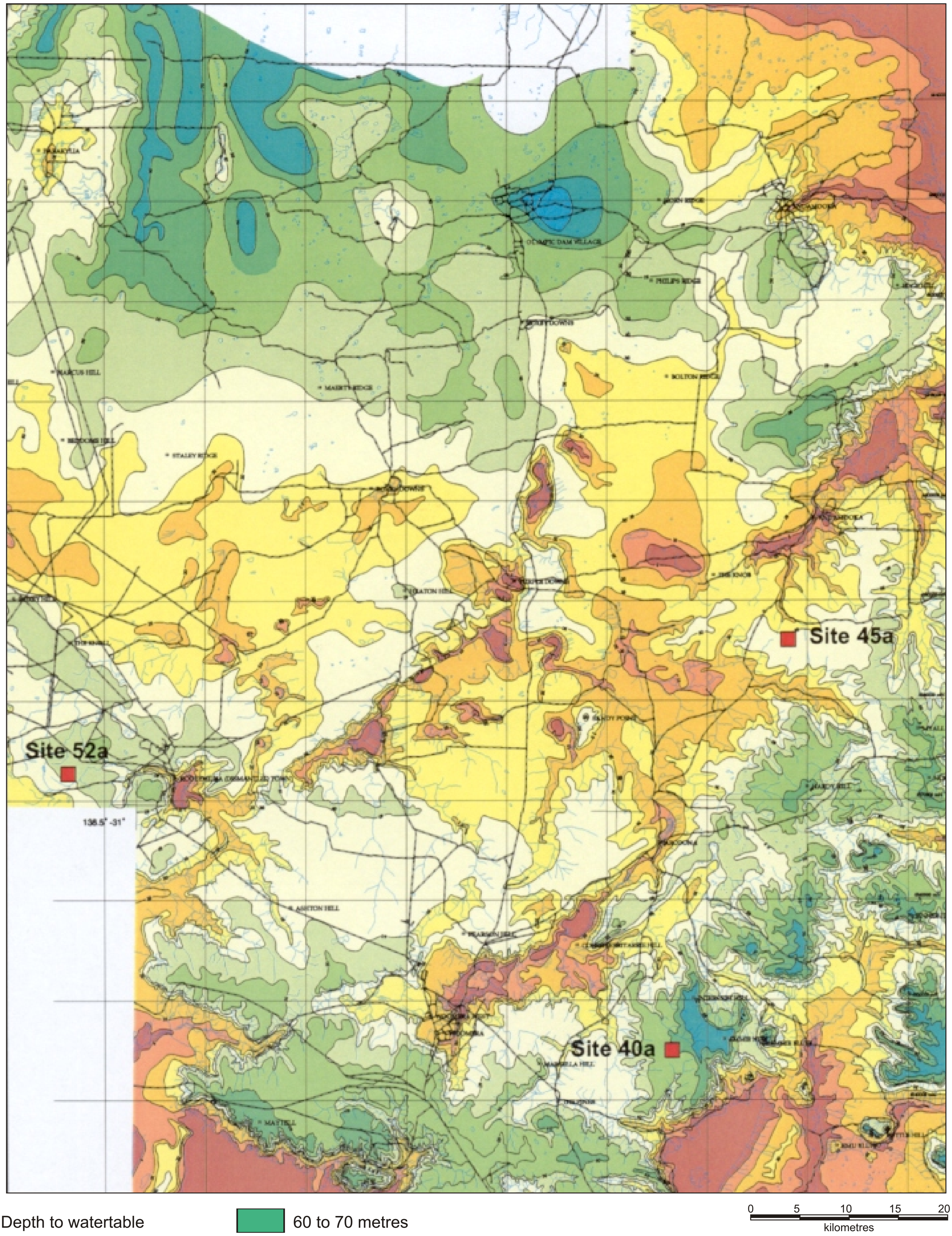
Fresh to brackish stock waters are obtained from the Kco–Ja and CPb aquifers in the west and southwest, but water quality in Kco deteriorates northward toward the Lake Eyre drainage divide, and eastward along regional flowlines in the Permian sediments. The majority of the #a and @ws–@wc aquifers yield waters which are too saline for stock. Distribution of salinity is shown in Figure 8.6 (Kellett et al. 1999).

There are substantial areas in the northwest, central and eastern parts of the study area which satisfy suitability criteria for a repository related to depth of watertable, groundwater salinity and residence times. The area containing Sites 52a, 40a and 45a is in the eastern part of the area studied by Kellett et al. (1999), and is considered in more detail below.

8.5.2 Subregional Hydrogeology

Sites 52a, 40a and 45a are within the geological Stuart Shelf area. The regional brackish to saline aquifer is developed in sedimentary rock of the Stuart Shelf, particularly @ws–@wc. The regional aquifer ultimately discharges into Lake Torrens or smaller salt lakes, or to the Olympic Dam mine. It can reasonably be assumed that the active groundwater flow system does not extend deeper than the top of the Woomera (or Tregona) Shale, the hydraulic conductivity of which appears to be extremely low (Kinhill Engineers 1997).

Although this regional aquifer conducts water mainly though fractures and other preferred pathways, on the scale of the Stuart Shelf it may reasonably be expected to behave as a single, continuous regional flow system rather than a compartmentalised system. Note, however, that on the scale of individual sites the primarily fractured rock aquifer characteristics of these formations may provide a better conceptual guide to local aquifer behaviour.



Depth to watertable

- 🟫 Less than 5 metres
- 🟧 5 to 10 metres
- 🟧 10 to 20 metres
- 🟨 20 to 30 metres
- ▭ 30 to 40 metres
- 🟩 40 to 50 metres
- 🟩 50 to 60 metres
- 🟩 60 to 70 metres
- 🟦 70 to 80 metres
- 🟦 80 to 90 metres
- 🟦 90 to 100 metres
- 🟪 More than 100 metres
- ☐ No more data
- 〰 Surface drainage features
- 〰 Roads
- ☒ Locality

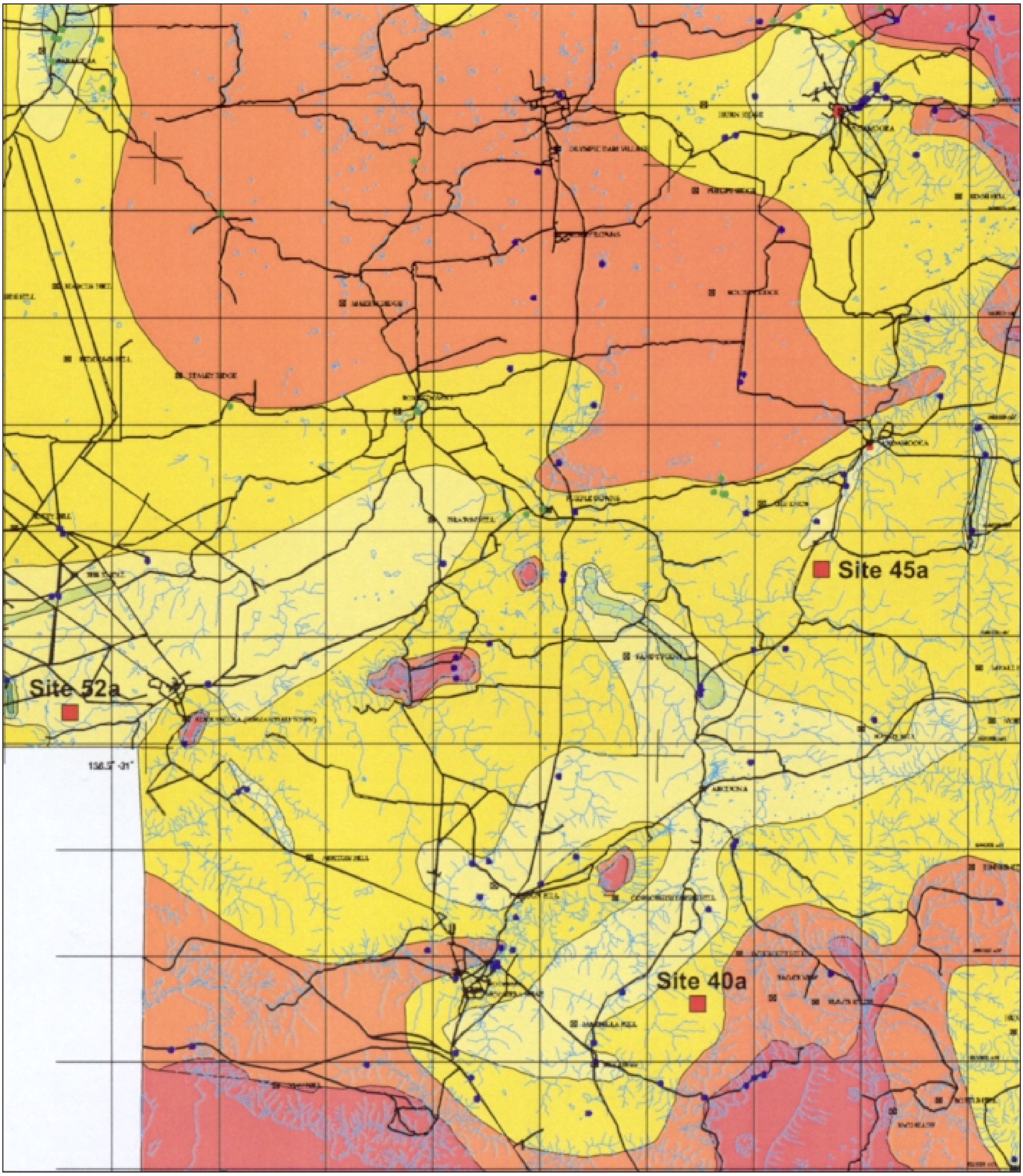
Projection: Australian Map Grid, Zone 53

Geology derived form the Stuart Shelf Geoscientific GIS Dataset, Minerals & Energy, SA, 1998

Topographic and cultural features after the TOP02150k Dataset, AUSLIG, 1996

Produced by the Land & Water Science Division, BRS, 1999

FIGURE 8.5
Central–north South Australia
Depth of watertable contours



Salinity of unconfined aquifer (mg/L TDS)

- 🟦 Less than 1500: potable, irrigation
- 🟩 1500 to 3000: all classes of livestock, limited irrigation
- 🟩 3000 to 7000: most livestock (not poultry, pigs, horses)
- 🟨 7000 to 12,000: some livestock (beef cattle, sheep on saltbush diet)
- 🟨 12,000 to 20,000: emergency rations for adult sheep for short periods only
- 🟧 20,000 to 30,000: limited industrial use, most ore processing
- 🟥 More than 30,000: limited industrial use, some ore processing, brine production if TDS>100,000 mg/L

- ☐ No data
- ● Bores within Cz aquifer
- ● Bores within Ja–Kco aquifer
- ● Bores within Єa aquifer
- ● Bores within ꟼC–ꟼb–ꟼw aquifer
- Surface drainage features
- Roads
- ⊠ Locality

0 5 10 15 20
kilometres

Projection: Australian Map Grid, Zone 53

Geology derived form the Stuart Shelf Geoscientific GIS Dataset, Minerals & Energy, SA, 1998

Topographic and cultural features after the TOP02150k Dataset, AUSLIG, 1996

Produced by the Land & Water Science Division, BRS, 1999

FIGURE 8.6
Central–north South Australia
Groundwater salinity

The regional watertable at all three sites and their surrounds lies generally within the Proterozoic @wc. At Site 52a only, the lower few metres of the overlying Cretaceous Kco is also saturated. This is a local phenomenon and not hydraulically connected to the extensive aquifers of which this formation is part in the Great Artesian Basin to the north.

@wc is underlain by the Woomera (or Tregona) Shale at all sites, although the base of the @wc was not encountered during drilling at Site 45a. The depth to watertable measured in 2000 and 2001 at the three sites is shown in Table 8.4. Note that a smaller number of wells were measured in August 2001 compared to September 2000. At all three sites the watertable was encountered deeper than the 25 m below ground level (bgl) for a 20 m deep disposal trench as required by site criterion b (see Section 5.1.1 and Table 5.2).

TABLE 8.4 Depth to watertable, Sites 52a, 40a and 45a

	Site 52a	Site 40a	Site 45a
September 2000 (inner square)	40.0–44.6 m bgl	63.6–68.7 m bgl	41.8–55.5 m bgl
August 2001	38.8–42.6 m bgl	65.3–68.0 m bgl	51.2–54.2 m bgl

Source: 2000 data courtesy Bureau of Rural Sciences (2001b), 2001 data collected by PPK

Regional groundwater flows preferably through distinct facture zones, and rises in an observation well to equilibrate with the regional watertable. The @wc aquifer is unconfined at Sites 45a and 52a and appears to be partially confined at Site 40a (by lower-permeability zones of the same formation).

Yields from all bores drilled during Stage 3 investigations (Bureau of Rural Sciences 2001b) were low (<1 L/s) and salinities were high, ranging from approximately 8000 to 26,000 mg/L total dissolved solids (TDS), with the majority greater than 20,000 mg/L.

All Sites

As part of Stage 3 Assessment drilling (Bureau of Rural Sciences 2001b) at each of Sites 52a, 40a and 45a, eight geological investigation bores in the inner square were converted to piezometers. Hydraulic tests using the ‘slug test’ method were undertaken at four wells at each site, and interpreted by the Hvorslev (1951) method using Waterloo Hydrogeologic Inc’s AquiferTest software (version 2.01). Full details are given in Appendix C3. The results are summarised below. Where a distinct change in behaviour was apparent, the calculated hydraulic conductivity for both early and late data is provided. Note that slug tests typically underestimate hydraulic conductivity, and results should be considered indicative only.

8.5.3 Site 52a

The groundwater flow direction at Site 52a is southwest to northeast (Appendix C1), sympathetic with the topographic gradient. The head drop is 10 m over 1.5 km with a fairly uniform hydraulic gradient of 1:150 (0.7%), apart from a southwest–northeast groundwater ‘mound’ in the inner square. The mounding develops where the watertable switches from @wc to Kco, and indicates that the fractured @wc is probably more permeable than the basal section of Kco.

Site 52a lies a few kilometres north of a major groundwater divide — the regional flow line through the site is about 100 km long, heading northeast toward Olympic Dam and beyond that to its discharge zone in Lake Torrens. The lateral groundwater velocity beneath Site 52a is estimated to be around 20 m/yr. Airlift yields are reasonably consistent at around 0.4 L/s and the groundwater salinity is uniform over the study area, averaging 16,000 mg/L total dissolved solids. The results of hydraulic tests are summarised in Table 8.5.

TABLE 8.5 Hydraulic test results, Site 52a

Drillhole	Hydraulic conductivity (m/s)	Notes
52a15NW	2.0×10^{-7}	Early data
	1.4×10^{-8}	Late data
52a50E	3.5×10^{-7}	Early data
	2.4×10^{-8}	Late data
52a50W	9.9×10^{-7}	One interpretation only
52a50S	9.4×10^{-8}	Early data
	2.7×10^{-8}	Late data

See Appendix C3 for details

8.5.4 Site 40a

The groundwater potentiometry at Site 40a (Appendix C1) indicates a dominantly southwest groundwater flow. The groundwater level drops by about 5 m over 1500 m, that is an average gradient of approximately 1:300 (0.3%). The gradient appears to be steeper in the southwest compared to the northeast. The salinity across the outer square ranges from about 25,000 mg/L in the north to 15,000 in the southwest. The results of hydraulic tests are summarised in Table 8.6.

TABLE 8.6 Hydraulic test results, Site 40a

Drillhole	Hydraulic conductivity (m/s)	Notes
40a15N	1.6×10^{-7}	One interpretation only
40a50SE	4.9×10^{-7}	Early data
	1.9×10^{-7}	Late data
40a50NE	5.7×10^{-6}	Early data
	3.2×10^{-6}	Late data
40a15NW	8.2×10^{-7}	Early data
	3.2×10^{-7}	Late data

See Appendix C3 for details

8.5.5 Site 45a

The groundwater potentiometry at Site 45a (Appendix C1) indicates a dominantly southwest to northeast and east groundwater flow direction. The flow lines switch from northwest to east along the northern edge of the outer square. Site 45a lies very close to a major groundwater divide in a flow field, with the regional flow direction to the north then northeast and discharge ultimately into Lake Torrens, 25 km to the northeast. There is a head drop of 3 m across the outer square and the hydraulic gradient ranges from 1:170 in the southeast quadrant to 1:400 along the southwest–northeast diagonal.

The change in hydraulic gradient probably reflects a permeability contrast in @wc. The groundwater 'drain' running in an arc from drillhole 45a15SW through 45a50NW to 45a15NE (Appendix C1) suggests this is a zone of higher permeability (increased fracturing) because of the low gradient and the comparatively higher airlift yields obtained from these piezometers. Assuming a 'background' hydraulic conductivity of 0.05 m/d and 0.1 m/d for the more permeable section, and an effective porosity of 0.01 m^3/m^3, a lateral groundwater velocity of around 10 m/yr is indicated for Site 45a.

The groundwater salinity at Site 45a shows the greatest variation of the three sites investigated. Total dissolved salts range from 23,000 mg/L in the west of the outer square to between 8000 and 9000 mg/L on the eastern side (Appendix C1). The potentiometry indicates that the pod of ‘fresher’ water in the east cannot represent local recharge — it may be a pulse from an abnormally large rainfall event which occurred over a century ago and has travelled as an unmixed package down gradient, or it may simply be an artefact of less salts available for dissolution in the aquifer in the eastern part of the study area. The results of hydraulic tests are summarised in Table 8.7.

TABLE 8.7 Hydraulic test results, Site 45a

Drillhole	Hydraulic conductivity (m/s)	Notes
45a15SW	2.0×10^{-6}	One interpretation only
45a50E	2.8×10^{-8}	Early data
	1.2×10^{-8}	Late data
45a50NW	3.1×10^{-7}	Early data
	4.2×10^{-8}	Late data
45a15NE	3.8×10^{-7}	One interpretation only

See Appendix C3 for details

8.5.6 Groundwater Recharge

Water Balance Method

Australian Nuclear Science and Technology Organisaiton and CSIRO (1998) undertook water balance calculations for conditions expected in the project area. Three sets of calculations were undertaken using data and properties inferred from two typical soil profiles, and 27 years (1969–96) of daily meteorological data from Woomera. One profile is applicable to a sand-dune system and the other to soils more typical of the three sites of the current project area.

The extensively tested Soil Water Infiltration and Movement (SWIM) model (Verburg et al. 1996) was used to simulate the infiltration of rainfall and its subsequent fate in the root zone of a soil. For each type of climatic data, infiltration was measured in the presence or absence of vegetation and the presence or absence of a cryptogram crust, and in a soil without vegetation. The calculations were restricted to a maximum depth of 1.0 m on the grounds that existing vegetation cannot extract water from below this depth. Movement of water below 1.0 m is assumed to continue, eventually, to the permanent watertable some tens of metres below.

Full results are given in the report by Australian Nuclear Science and Technology Organisaiton and CSIRO (1998). Calculated water balances for the two soils present in the project area, based on the SWIM calculations for the period 1969–96, are given in Table 8.8 below.

The SWIM calculations show low deep infiltration (groundwater recharge) for the two soils under the natural, vegetated state. In the case of no vegetation, a large increase in deep infiltration is predicted for the Solonetz soil (4 orders of magnitude) whilst the increase for the medium clay soil is negligible.

It should be noted that individual wet years account for the majority of runoff calculated for the site over the years examined. For example, during the wettest year in the sequence, 1974, more than 50% of the deep infiltration and 30% of the surface runoff for the entire 27-year period was simulated.

TABLE 8.8 Calculated water balances based on the SWIM calculations for the period 1969–1996, typical soils of the project area

Case	Soil	Deep drainage	Surface runoff
Vegetated	Solonetz soil	0.0016 mm/yr	3.2 mm/yr
	Medium clay soil	0.0015 mm/yr(1)	4.4 mm/yr
No vegetation	Solonetz soil	1.08 mm/yr	3.7 mm/yr
	Medium clay soil	0.0015 mm/yr	16.4 mm/yr

(1) Typographical error in original table by Harries et al. 1998 showed 0.0005 mm/yr.
Source: Australian Nuclear Science and Technology Organisaiton and CSIRO (1998)

The data offer an estimate of the transit time of water moving from the repository if the capped repository acted in a similar manner. Assuming a water content in the unsaturated zone of 0.1 m^3/m^3 and a recharge rate of 0.0015 mm/yr, the transit time for passage of water though 50 m is in the order of 10^6 years. Alternative approaches have confirmed the order of soil water movement and groundwater recharge expected at the sites. The engineered cap of the repository as it would be built is expected to be lower again, with an increased passage time.

Chloride Mass Balance — Saturated Zone

Chloride mass balance in the saturated zone (groundwater) is the simplest technique for recharge estimation. The method assumes one-dimensional piston flow and produces a long-term average. Details are given in Appendix C2, which is an excerpt of Bureau of Rural Sciences 2001b.

The chloride mass balance method gives a recharge rate of 0.06 mm/yr at Sites 40a and 45a, and 0.09 mm/yr at Site 52a. The wetting front velocity is about 6 mm/yr at Sites 40a and 45a, and 3 mm/yr at Site 52a. Hence, it would take 11,000 years for infiltration through the 67 m-thick unsaturated zone at Site 40a, 9000 years to infiltrate the 55 m-thick unsaturated zone at Site 45a and 14,000 years through 41 m of unsaturated zone at Site 52a, based on this estimation method.

Chloride Mass Balance — Unsaturated Zone

Full details of these calculations are given in Appendix C2.

Using the measured chloride and moisture characteristics flow recharge and assuming a constant chloride flux rate through time, a reasonably uniform recharge of 0.02 mm/yr for Site 40a was estimated.

Using the same assumptions, recharge rates of 0.02 mm/yr for drillhole 45a15SE were indicated, whereas 45a15NW gave a recharge rate of 0.02 mm/yr through the surface clay, but an apparent rate of 0.17 mm/yr through @ws. This seems to indicate preferential flow or possibly a different palaeo-recharge regime, a reflection of the marked salinity variations in the unsaturated zone across the site.

At Site 52a, mass balance calculations give a recharge rate of 0.03 mm/yr for drillhole 52a15NE and 0.05 mm/yr for 52a15SW (Kmb and upper Kco).

Groundwater Age Estimation using Isotopes

The radioisotopes chlorine-36 (^{36}Cl) and carbon-14 (^{14}C) have half-lives of 300,000 and 5730 years, respectively. Nine regional groundwaters were analysed for ^{36}Cl by accelerator mass spectrometry at the Australian National University; 10 samples were analysed for ^{14}C by counting at CSIRO (Appendix C2).

In summary, the radioisotopes ^{14}C and ^{36}Cl indicate that groundwater in the region is at least 20,000 years old, with much of it being much older, particularly to the south and east where waters appear to be in excess of 100,000 years old. Within the analytical limits of the measurement techniques, and the inherent variability of radioisotope concentrations in nature, more precise numbers than this cannot be interpreted.

Recharge Processes Indicated by Deviation of the Stable Isotopes $\delta^{18}O$ and δD from the Meteoric Water Line

Oxygen-18 (^{18}O) and deuterium (D) are isotopes that occur naturally in all waters and are useful tracers of water movement and history (from Bureau of Rural Sciences 2001b). Results indicate evapotranspiration of infiltrating rainwater prior to recharge of the aquifers. The samples from Site 52a are heavier (i.e. more evaporated) than those from Sites 45a and 40a (there was only one sample collected from Site 40a). This implies lower recharge rates at Site 52a although this cannot be quantified.

Summary of Recharge Rates and Groundwater Residence Times

Comparisons of recharge rates estimated by chloride mass balance in the saturated and unsaturated zones are shown in Table 8.9. Also shown are estimated and observed groundwater ages based on residence times in the unsaturated zone under conditions of one-dimensional vertical piston flow-type recharge.

TABLE 8.9 Recharge rates and groundwater ages / residence times

	Recharge rates (mm/yr)		
Method	**Site 40a**	**Site 45a**	**Site 52a**
Cl mass balance (sat. zone)	0.06	0.06	0.09
Cl mass balance (unsat. zone)	0.02	0.02–0.17(1)	0.03–0.05
	Residence times in unsaturated zone (years)		
Method	**Site 40a**	**Site 45a**	**Site 52a**
Cl mass balance (sat. zone)	11,000	9000	14,000
Cl mass balance (unsat. zone)	33,000	3000(1)–27,000	25,000–42,000
^{14}C	n.a.	>30,000	>30,000 (52aSE) 29,000 (52aNW)
^{36}Cl	n.a.	<100,000	n.a.

(1) Probably via preferential flow path
Source: Bureau of Rural Sciences 2001b (see Appendix C2)

There is a discrepancy between the recharge rates estimated by chloride mass balance in the saturated and unsaturated zones. More credibility should be placed on the unsaturated zone analyses, especially for Site 52a. The chloride and moisture versus depth patterns, and the linearity of the cumulative chloride profile, support the assumption of piston flow-type recharge at Site 52a. These plots also indicate the presence of a diffusion gradient to a fresher watertable.

8.6 Climate

Climatic effects need to be considered in assessing the factors that may influence the integrity and storage of radioactive waste. Climate can affect storage facilities in various ways, for example changes and extremes in rainfall and temperature, variation in soil moisture content, fluctuation in surface and aquifer watertables, and soil erosion by winds and floods (Appendix F). These factors could also influence the vegetation in the region.

The three primary climate issues of particular relevance to the repository are greenhouse-induced climatic change, natural climatic variation and long-term climate perturbations (on the multi-millennium scale) (Appendix F).

Air movements and thermal structure of the local atmosphere may also offer a pathway for any released radionuclides to be transported to residential areas.

8.6.1 Climate and Winds

South Australian seasonal variation of weather is controlled by the position of the subtropical ridge of the high-pressure system. During summer this ridge is located at latitudes south of the Australian continent. Anticyclonic high-pressure systems normally move eastwards along the ridge, resulting in more frequent airstreams from the southeast to east. In autumn the ridge moves north and remains over the continent for most of the colder months, resulting in more frequent northwest to southwest wind directions (Bureau of Meteorology 1998). The climate of South Australia during winter is heavily influenced by cyclonic low pressure fronts associated with this northerly ridge.

The Bureau of Meteorology has been collecting weather data from weather stations at Woomera since the 1940s and Andamooka since the 1960s. The Woomera weather station is the closest to Sites 40a and 52a (approximately 23 km west of 40a and 50 km southeast of 52a). The Andamooka weather station lies approximately 48 km north of Site 45a. Additional weather information is available from five weather stations at the Olympic Dam mine, approximately 50 km north of Site 45a and 30 km west of Andamooka, collected by WMC (Olympic Dam Corporation) and dating back to 1980 (Kinhill Engineers 1997). Figures 7.1 and 7.2 show these locations in relation to the proposed repository sites.

The Bureau of Meteorology weather stations record daily maximum temperatures for 24 hours from 9 am, and daily minimum temperature and rainfall for 24 hours up until 9 pm. A ‘rainday’ is defined as a day with a rainfall of at least 0.2 mm. The median (decile 5) monthly rainfall is given as a preferred and more reliable indicator of ‘average’ rainfall as it is less influenced by the high variability of daily rainfall. Both sites have temperature and rainfall data for at least 30 years. Wind speeds are recorded on three-hourly bases and averaged for each season.

Summaries of the relevant weather data for Woomera and Andamooka are presented in Tables 8.10 and 8.11, respectively. Most elements are calculated for months that have more than 20 days of observations, and not all the variables have been collected for the full period of operation.

The climate of central–north South Australia is generally characterised by low rainfall, low relative humidity, high evaporation and high temperatures during summer. Woomera and Andamooka experience mild to cool winters and warm to hot summers, with annual average maximum and minimum temperatures around 26 °C and 13 °C, respectively.

Rainfall for the general area is irregular, year round and low, with total median rainfall around 177 mm. The average relative humidity in the region is around 43%. Woomera data indicate strong periodicity in evaporation, which is directly related to seasonal temperature and solar radiation levels. On average, the region experiences high evaporation levels of approximately 250 mm per month.

Heavy rainfall events can occur in any month, with a tendency towards highest monthly rainfall occurring mostly during warmer months. Significant rainfall events in the study area are usually a result of large-scale weather systems, involving closed cyclonic circulation in the upper atmosphere and a surface low-pressure system, with the inflow of moist tropical air during summer. Occasional surface anticyclone high-pressure systems can also result in similar rain-producing conditions during winter (Jensen and Wilson 1980).

TABLE 8.10 Summary of atmospheric measurements, Woomera aerodrome, 1949–2001 (Bureau of Meteorology)

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean daily maximum temperature (deg C)	34.2	33.6	30.4	25.3	20.4	17.3	16.8	18.7	22.3	26.0	29.5	32.2	25.5
Mean daily minimum temperature (deg C)	19.3	19.3	16.8	12.9	9.4	6.7	5.8	6.7	9.3	12.3	15.1	17.6	12.6
Mean 9 am relative humidity (%)	43	46	50	55	68	76	74	66	53	45	42	42	55
Mean 3 pm relative humidity (%)	22	24	26	32	41	46	43	37	30	26	22	22	31
Mean 3 pm wind speed (km/hr)	17.7	16.6	15.9	15.2	15.9	16.9	18.3	19.9	20.5	20.6	19.1	18.7	17.9
Median (5th decile) monthly rainfall (mm)	9.5	9.9	3.9	6.4	11.5	10.7	11.2	10.2	10.3	8.9	11.2	7.8	175.2 (Total)
Highest monthly rainfall (mm)	93.0	121.2	191.2	68.8	119.4	65.2	64.7	72.6	85.9	82.4	130.6	85.6	
Lowest monthly rainfall (mm)	0	0	0	0	0	0	0	0	0.4	0	0	0	
Mean no. of raindays	3.0	2.5	2.6	2.8	5.1	5.3	6.0	5.5	5.2	4.5	4.4	3.3	50.1 (Total)
Mean daily evaporation (mm)	14.1	13.1	10.2	6.7	4.1	2.9	3.1	4.6	6.7	9.3	11.6	13.2	8.3

TABLE 8.11 Summary of atmospheric measurements, Andamooka, 1965–2001 (Bureau of Meteorology)

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean daily maximum temperature (deg C)	36.1	35.5	32.2	27.0	22.2	18.6	18.3	20.4	24.3	27.9	31.5	34.5	27.4
Mean daily minimum temperature (deg C)	21.0	21.2	18.3	13.7	9.9	6.8	5.8	7.2	10.3	13.5	16.8	19.4	13.7
Mean 9 am relative humidity (%)	40	42	45	49	62	72	70	60	48	41	41	39	51
Mean 3 pm relative humidity (%)	21	24	25	29	39	44	41	34	27	24	23	21	30
Mean 3 pm wind speed (km/hr)	12.4	11.4	10.4	9.6	9.3	9.2	10.9	12.8	13.9	14.3	12.8	12.3	11.6
Median (5th decile) monthly rainfall (mm)	17.0	10.4	5.4	4.1	10.0	7.8	12.2	9.8	7.7	8.6	11.7	10.8	179.2 (Total)
Highest monthly rainfall (mm)	104.5	100.2	231.1	87.6	89.4	66.0	49.3	46.3	43.1	87.6	55.4	125.1	
Lowest monthly rainfall (mm)	0	0	0	0	0	1.4	0	0	0	0	0	0	
Mean no. of raindays	3.6	2.5	2.3	2.3	3.7	4.3	4.6	4.5	4.3	3.9	3.9	3.0	42.9 (Total)

Storm frequency event data have been estimated (Table 8.12) for Woomera using Institution of Engineers Australia methodology (Canterford 1987; Pilgrim 1997).

South Australia has experienced a total of fifteen significant droughts since 1859, most of which were generally restricted to inland areas. Flooding is less common in the generally dry climate and low relief of South Australia (Bureau of Meteorology 1998).

TABLE 8.12 1-in-100-year storm event frequency — Woomera

Duration	Intensity (mm/hr)
5 min	205
1 hr	59.6
12 hr	9.7
24 hr	5.5
72 hr	2.1

Data from the Olympic Dam mine weather stations indicate that barometric pressures do not vary greatly throughout the year but there is a general trend for higher pressures during winter (Kinhill Engineers 1997).

Figures 8.7 and 8.8 represent seasonal wind roses for Woomera (1949–2001) and Andamooka (1969–2001). Autumn is defined as March–May, winter as June–August, spring as September–November and summer as December–February. The size of the central circle on each rose is proportional to the number of calms per season (see scale).

The most frequent wind directions experienced by both stations for summer and autumn are predominantly southerly to southeasterly. During winter and spring winds tend to be more variable, with increased northern and western components during winter. Spring winds are rotating south, shifting towards the summer and autumn conditions, with increased southwesterly and southerly winds. Winds are generally light to variable, with an annual mean wind speed of 17.9 km/hr for Woomera (Table 8.10) and 11.6 km/hr for Andamooka (Table 8.11). In general, Woomera experiences stronger winds and less calms than Andamooka.

8.6.2 Projected Climatic Changes and Potential Impacts on Repository

The Earth’s climate fluctuates naturally from year to year and decade to decade, without any anthropogenic or external influences.

The greenhouse effect (global warming) is caused by atmospheric gases trapping heat in the atmosphere, resulting in a steady increase in the Earth’s temperature. Increasing concentrations of gases such as carbon dioxide (CO_2), ozone, methane, nitrous oxide and chlorofluorocarbons enhance the greenhouse effect. Of these gases, CO_2 is the most important contributor. It is estimated that six billion tonnes of CO_2 are currently released into the Earth’s atmosphere every year (Appendix F). It is further projected that this annual release could triple over the next century, considerably increasing the greenhouse effect.

CSIRO conducted a wide-ranging assessment of the possible range of future climatic changes in the Woomera region, with specific emphasis on the variables relevant to the proposed national repository Appendix F.

Climatic changes were modelled for a range of possible scenarios, to accommodate a range of levels of future atmospheric concentrations of active greenhouse gases (primarily CO_2) The report predicted (with a high level of confidence) an increase in surface temperature of around 4°C (superimposed on interannual natural temperature fluctuations) by the end of this century under an enhanced greenhouse effect.

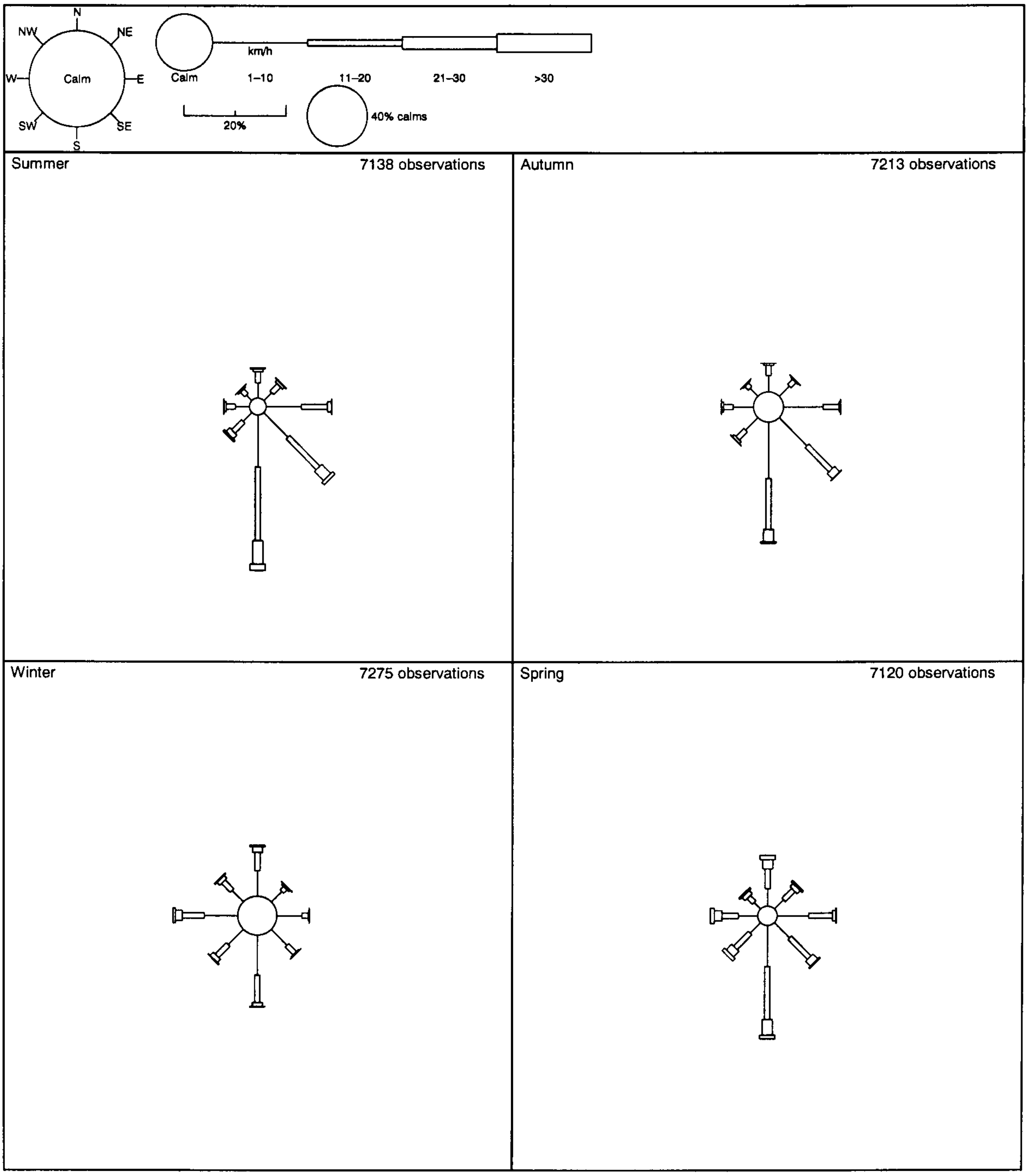


FIGURE 8.7

Wind roses for Andamooka using available data 1969–2001

(Site number 016065, Locality – Andamooka, Opened Jan 1965, Still open, Latitude 30°27'01"S, Longitude 137°10'05"E, Elevation 76 m are included.

— Prepared by Climate and Consultancy Section in the South Australian Office of the Bureau of Meteorology

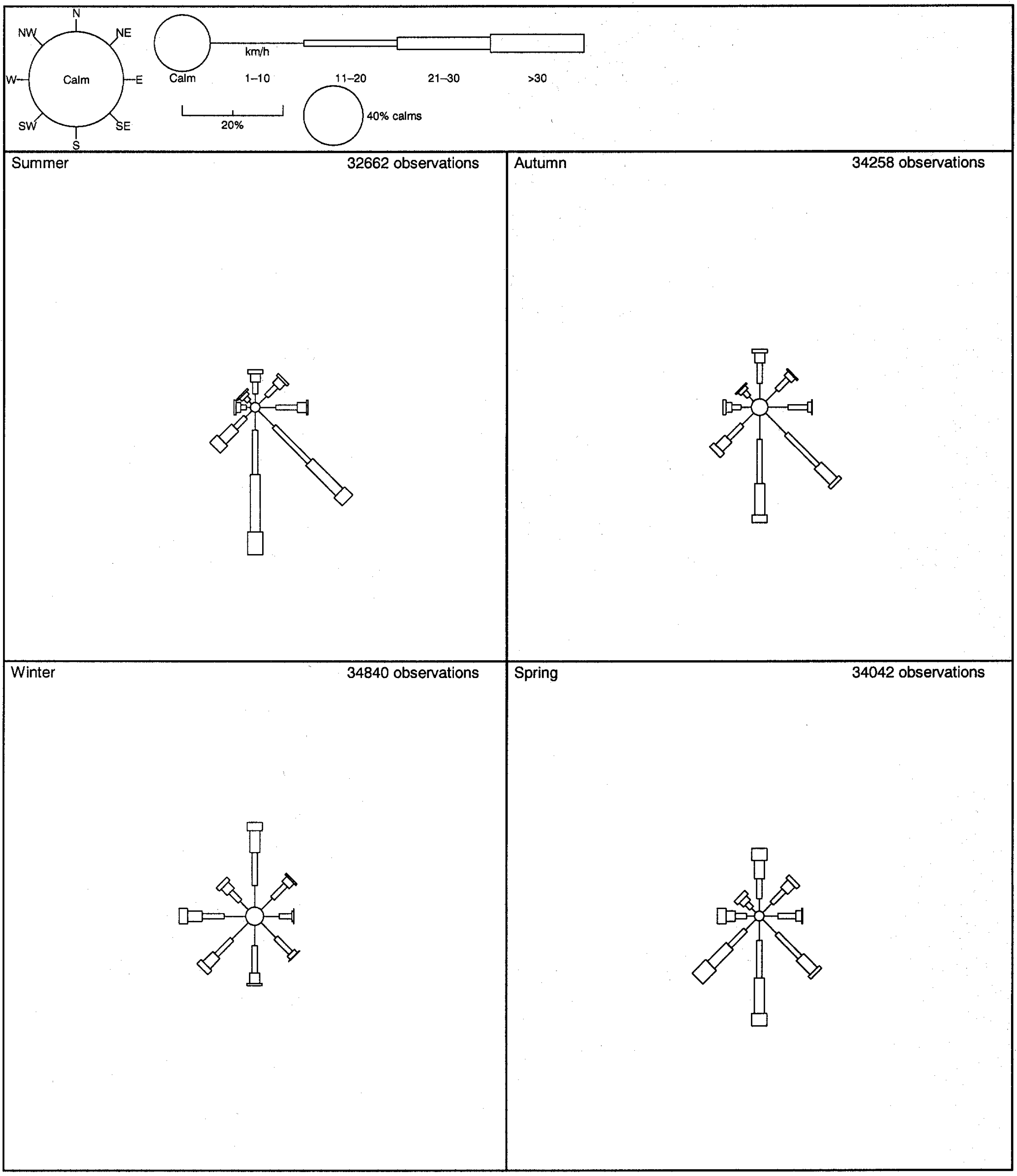


FIGURE 8.8

Wind roses for Woomera aerodrome using available data 1949–2001

(Site Number 016001, Locality – Woomera, opened Jan 1949, still open, Latitude 31°09'26"S, Longitude 136°48'12"E, Elevation 166.6 m are included)

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A small increase in rainfall is also projected for the Woomera area. The magnitude of this increase varies considerably with marked interannual variability, depending on the various projected increases in CO_2 that were modelled. An increased frequency of more intense rainfall events is also predicted, which could cause an increase in rain-induced soil erosion compared to present low erosion levels. However, because of the predicted elevated temperatures, the moisture content of the soil is not expected to change markedly, resulting in a continuation of the present marginal vegetative cover.

Mean annual surface-wind velocities are not predicted to increase in the Woomera region. Current levels of wind erosion are therefore not expected to increase under global warming.

Predictions indicate no substantial changes in external forcing mechanisms of climatic variation such as solar perturbations, volcanic eruptions or changes in the Earth’s orbital properties within the next 10,000 years. Changes induced by natural climatic variability are unlikely to be sufficient to affect the viability of the proposed repository.

8.7 Air Quality

The vertical air temperature profile also plays an import role in the dispersion and transport of suspended particles (e.g. radionuclides in dust particles). Atmospheric stability influences the horizontal and vertical mixing of air. Stable conditions create vertical stratification with reduced atmospheric mixing, which, in turn, increases the probability of inversion layers. Low level (100–400 m) nocturnal inversion layers have been observed to predominate at Olympic Dam, and are associated with clear night skies and light winds.

Under these conditions, gaseous emissions tend to be concentrated below the inversion layer. As the sun rises, surface heating due to solar radiation generates vertical convective currents, creating unstable ground level conditions. As the ground heats further, this mixed layer grows in height until it reaches the inversion layer and causes the concentrated pollutants to rapidly mix to ground level. Emissions at ground level typically reach their highest concentrations under such conditions.

Air quality data have been collected at the Olympic Dam mine and predictions modelled for the expansion of the mine (Kinhill Engineers 1997).

The proposed sites are all remote from any significant sources of artificial atmospheric pollution. The *Environmental Protection (Air Quality) Policy 1994*, as declared under the *Environment Protection Act 1993*, states the maximum pollution levels for industrial air pollution. The construction and operation of the repository are unlikely to cause any significant air pollution, apart from minor dust emissions during construction. Dust during construction would be controlled by standard methods such as water application in working areas.

Overall, dust emissions during construction would be minor compared with dust generation from a short section of any of the unsealed roads in the arid areas, and is not considered further in this Draft EIS.

The radiological environment and potential impacts of emissions of radionuclides to the atmosphere are discussed in Chapter 12, and an assessment of background levels of atmospheric radioactivity is presented in Appendix E3.

8.8 Noise

The repository site would be remote from all major sources of artificial noise, and noise generated during construction and operation is unlikely to be of any significant disturbance to rural settlements or residential areas.

The *Environment Protection Act 1993*, responsible for the control of excessive noise exposure for people, stipulates that restrictions are imposed on noise levels where industrial activities are located near residential areas. The closest major residential settlements to the proposed sites are approximately 23 km west of Site 40a (Woomera), 50 km southeast of Site 52a (Woomera) and 42 km northwest of Site 45a (Roxby Downs).

Noise generated from the repository would be from the following sources:

- machinery used during digging and construction
- vehicles associated with delivery and transport of waste.

The level of noise generated from the above activities is unlikely to be in excess of noise generated by normal pastoral activities in the region and, in the case of Site 52a, by activities in the Woomera Prohibited Area (WPA), and is not considered further in this Draft EIS.

8.9 Fire Regimes

In arid Australia fire regimes were implemented by Aborigines and Europeans to maintain a vegetation community for a particular purpose, for example hunting and gathering and to enhance grazing by stock (Flannery 1994). These regimes targeted hummock grasslands and savannah woodlands, that is communities whose species are generally adapted to fire.

Within northern South Australia exceptional rainfall was recorded in 1973 and this encouraged exceptional growth of annual and ephemeral plants, especially grasses. After curing, this resulted in the accumulation of a large quantity of inflammable matter across much of the region. Lay (1976) provides a summary of subsequent fires over the period 1974–76.

Within the project area, bushfires occurred near Andamooka Homestead, within the WPA west of Site 52a, and on South Oakden Hills, south of the Stuart Highway, with most occurring in savannah woodland and grassland. No major bushfires have been recorded on the Arcoona Tableland since the 1950s (Donovan 1995). The chenopod low shrubland that dominates the Arcoona Tableland is comparatively inflammable and its component perennial species are not well adapted to fire. McArthur (1972) indicates that fires are extremely infrequent in this community.

In conjunction with Defence, the Pastoral Management Board has undertaken trials on the flammability of saltbush and the propagation, behaviour and management of fire in chenopod shrublands on the WPA (B. Lay, pers. comm. October 2001). These trials recorded that the fire spread slowly through the understorey grasses and dead shrubs and burned only small patches before self-extinguishing. Regeneration of perennial shrub species in the burned areas occurred but was slow.

The potential for fire to have any impact on the repository, given the very low potential combustibility of any of the wastes to be disposed of, is very low. The issue of fire is not considered further in this Draft EIS.

8.10 Impacts, Risks and Safeguards During Construction and Operation

Potential impacts and proposed environmental safeguards associated with development of the repository are included in the following summary table (Table 8.13). Additional details on key areas are provided in Sections 8.10.1, 8.10.2 and 8.10.3.

TABLE 8.13 Potential environmental impacts and safeguards during construction and operation

Issue	Management strategy
Potential impact	
Surface water runoff, soil erosion and siltation of watercourses	▪ Apply water used for dust suppression at a rate that would not generate significant runoff from the application area ▪ Install erosion and sediment control structures to ensure sediment transfer is minimised ▪ Locate soil stockpiles in designated areas away from drainage lines and install appropriate sediment control structures ▪ Carry out washdown of construction equipment on a hardstand within a bunded area and away from drainage lines ▪ Carry out refuelling of equipment on a hardstand away from drainage lines and within a bunded area ▪ Prepare a spill response plan prior to commencement of construction ▪ Construct surface water management ponds to enable storage and evaporation of surface water from construction operations ▪ Pump water that collects in trenches to the storage pond for evaporation ▪ Rehabilitate and revegetate disturbed areas not required for the operational period ▪ Minimise the amount of site disturbance beyond the limit of development works ▪ Minimise disturbance to natural soil profiles and removal of vegetation ▪ Maintain road surface without potholes or ‘bulldust’ patches ▪ Suspend construction activities following significant rain if additional soil damage is being incurred ▪ Control drainage through diversion to protect exposed areas as required ▪ Install temporary silt traps to remove sediment from site runoff before leaving site
Dust generation	▪ Restrict site access to dedicated roads ▪ Restrict vehicle speeds to 30 km/hr ▪ Apply water or other suitable medium to site roads and soil stockpiles to reduce the potential for dust generation
Noise	▪ Ensure consistency with South Australian Environment Protection Agency (EPA) Industrial Noise Policy ▪ Fit construction equipment with appropriate noise control devices where practical ▪ Ensure regular maintenance of construction equipment
Release of pollutants to soil, surface water or groundwater	▪ Ensure all fuel tanks/drums are stored in bunded areas ▪ Ensure clean-up procedures and equipment are in place and implemented in the event of spills

8.10.1 Slope Stability

During establishment of the repository there are potential risks to site workers associated with the stability of the excavations. A preliminary slope stability assessment indicates that the orientation of the joints would influence the stability of the repository walls. Establishing a slope angle parallel to the dominant dip of the joint would minimise the potential for significant slope failure. As excavation, filling and backfilling of the repository is expected to occur over a short period of time, steeper slope angles are feasible. Temporary support in the form of meshing and rockbolts may be required to ensure the safety of site personnel.

On the basis of information from bore logs, geotechnical testing, rock substance strength and orientation of joints; and on consideration of the short-term period that the excavation would be open, the following preliminary slope design parameters are recommended:

- surface silty gravelly sand, 1:4 (vertical:horizontal)
- sandy clay residual soil and extremely weathered rock, 1:2 (vertical:horizontal)
- rock slope:
  - Site 40a, 80 degrees (parallel to the main joint set)
  - Site 45a, 80 degrees (parallel to the main joint set)
  - Site 52a, 60 degrees.

Additional investigations would be undertaken to provide specific data on the orientation of major defects, to confirm the preliminary design slope angles.

8.10.2 Surface Water Infiltration

Surface water infiltration into the repository can occur from a number of scenarios:

- runoff during construction and operation of the facility
- infiltration of rainfall through the cap
- surface ponding of water on the cap due to settlement and subsequent infiltration.

During construction the surface adjacent to the slope would be graded away from the slope crest to minimise the potential for surface water to discharge into the excavation. Diversion drains would be established to divert up-catchment surface water generated from storm events away from the repository. This would ensure that there is no accumulation of surface water in the vicinity of the buried wastes or entry of surface water into trenches or boreholes both during operations and after closure. Surface drains from operational areas where radioactivity is handled would be led to an evaporation pond within the repository compound, to collect runoff and contain potentially contaminated surface water on site.

The completed repository surface would have a general slope in the order of 10% to minimise the potential for ponding and ensure erosion is not significant over the life of the repository (including the institutional period).

8.10.3 Water Infiltration

Repository Assessment

An assessment was undertaken to assess the possible risks and impacts of water infiltration and to refine the design of the cover material. This included:

- collection and laboratory analysis of soil samples for use as capping material
- hydrological model simulations using the US Environmental Protection Agency approved Hydrological Evaluation of Landfill Performance (HELP) model.

Standard geotechnical tests were conducted including Atterberg Limits (Plastic Limit, Liquid Limit, Plasticity Index, Linear Shrinkage), compaction, particle size distribution, Emerson dispersion and triaxial cell permeability tests.

The results indicate that the gravelly silty sand overburden material and weathered shale could be used to produce a homogeneous earthfill for placing as a cap over the repository. On the basis of the hydraulic conductivity tests this material would not be suitable for constructing a low permeability barrier layer in the cap. On the basis of the Atterberg Limits and particle size distribution it is considered that the sandy clay soil located near the surface should be suitable for use in the construction of a low permeability barrier layer with a permeability expected to be less than 1x10^{-9} m/s. Additional sampling and analysis would be undertaken as part of detailed design.

A series of hydrological model simulations using the Waterloo Hydrogeologic Inc. Unsat Visual HELP computer package were undertaken to assess the potential infiltration of rainwater through various capping and base lining system scenarios. The HELP model calculates the movement of water across, through and out of containment facilities.

A number of different capping and liner systems were assessed, including a low permeability clay barrier layer in the cap, a low permeability liner at the base of the repository, a homogeneous earthfill cap and a composite barrier layer in the cap (incorporating a geomembrane and low permeability compacted clay) (Table 8.14).

TABLE 8.14 Summary of cap and liner systems assessed using the HELP model

Case reference	Description	Low permeability liner at base of trench	Drainage layer in cap
1a	Homogeneous soil cap comprising 2.5 m of loamy sand and 2.5 m of sandy loam capping overlying waste	No	No
1b	Homogeneous soil cap comprising 5 m of sandy loam overlying waste with a low permeability clay barrier 0.6 m thick at the base of the trench	Yes	No
2a	Capping layer comprising 1 m of soil, 0.6 m of low permeability clay and 3.4 m of soil overlying the waste	No	No
2b	Capping layer of 1 m of soil overlying a composite liner comprising a geomembrane and 0.6 m clay barrier, and 2.6 m of soil overlying the waste	No	Yes
2c	Capping layer comprising 1 m of soil overlying a 0.6 m thick clay barrier and lateral drainage sand layer, 3.2 m of soil overlying the waste and a 0.6 m thick clay liner at the base of the repository	Yes	Yes
3a	Capping layer comprising 4.4 m of soil overlying a 0.6 m thick clay barrier	No	No
3b	As 3a above, but including a 0.6 m clay barrier at the bottom of the trench	Yes	No
4	Capping layer of 1 m of soil overlying a geomembrane, 4 m of soil overlying the waste, with a 0.6 m clay liner placed at the base of the trench	Yes	Yes

Input parameters for the model included weather data from the Woomera Aerodrome (temperature, precipitation and solar radiation) (see Section 8.6), soil and material parameters from the geotechnical laboratory test results and default parameters from the HELP model.

The assessment indicated low levels of infiltration for all cases examined, with the least infiltration experienced using a composite lining system located at the base of the cover layer. The results are summarised in the attached table (Table 8.15). Essentially, the modelling undertaken as part of the project assessment indicates that rainwater infiltration would be minimal with the assessed alternative covers.

Placement of a compacted clay barrier layer higher in the cover layer would be susceptible to cracking due to prolonged wet/dry cycles. Shallow clay barriers may also be susceptible to burrowing animals.

TABLE 8.15 Summary of annual percolation rates for 10-year modelled period, evaporative zone depth 0.3 m

Annual total percolation rates through base of repository (metres)										
Case reference	Year									
	1	2	3	4	5	6	7	8	9	10
1a	0	0	0	0.0013	0	0.0013	0.008	0.019	0.012	0.01
1b	0.00015	0.000125	0.00025	0.00031	0.00044	0.00048	0.0006	0.00064	0.00083	0.0023
2a	0.023	0.011	0.0013	0.013	0.001	0.0013	0.018	0.0012	0.009	0.035
2b	0.022	0.011	0.002	0.012	0.01	0.00055	0.019	0.0004	0.009	0.034
2c	0	0	0.0012	0	0.0012	0.0012	0.0012	0.0012	0.0012	0.0026
3a	0.022	0.005	0.009	0.011	0.01	0.0013	0.018	0.0013	0.009	0.026
3b	0.022	0.0117	0.0036	0.011	0.01	0.01	0.0006	0.0004	0.009	0.037
4	0.0004	0.00054	0.0007	0.0009	0.001	0.0011	0.00126	0.00135	0.0014	0.0019

On the basis of the assessment the recommended cover design includes the installation of a composite lining system incorporating a geomembrane liner (high density polyethylene) placed directly onto a compacted clay barrier layer located at the base of the 5 m cover layer. The geomembrane would also serve as a marker layer for the future and minimise potential intrusion by humans and burrowing animals. A geotextile membrane would be placed over the geomembrane to minimise the potential for damage and provide some lateral drainage. As part of the design phase an assessment would be carried out to determine the benefits or otherwise of installing a coarse cobble layer (rock material from the excavations) as an additional deterrent to burrowing animals.

The installation of a compacted clay liner at the base of the repository did not significantly alter the percolation rate through the repository. Nevertheless, it is proposed to compact the base of the repository and grade the finished surface to a sump to collect any free water and direct it to a sampling well.

Unsaturated Zone Assessment

Preliminary modelling of the movement of water through the unsaturated zone of soil and rock between the ground surface and the watertable in the project area suggested a transit time in the order of 60,000 years in the presence of vegetation and 6000 years in the absence of vegetation (Australian Nuclear Science and Technology Organisaiton/CSIRO 1998, 1999). These residence times are very long compared to the half-lives of key radionuclides in typical wastes (e.g. ^{137}Cs is 30 years). The same workers examined the adsorption and retardation characteristics of soil and rock samples. The majority of radionuclides that would be present in buried waste adsorb to a greater or lesser degree on the surfaces of soil and rock particles, which further slows their movement relative to the already slow movement of water through the unsaturated zone towards the watertable.

To further examine the movement of potential contaminants through the unsaturated zone, modelling of the movement of three selected radionuclides was undertaken for Site 52a. This study is presented in full in Appendix C5, and a synopsis is presented here.

The modelling was completed using Chemflo-2000, a one-dimensional water and solute modelling program. Simulations were completed for solute transport from the base of the waste repository during rain and storm periods for up to 100 years. Field and standard reference data were used.

The following radionuclides were modelled, covering the range of physico-chemical properties expected in the conditioned waste that it is proposed will be stored. A nominal (excessive) input concentration of 100 mg/L at the base of the repository was assumed.

- Tritium (^{3}H) is not significantly affected (retarded) by chemical processes, and moves with water flow. It does degrade reasonably quickly, with a half-life of 12.3 years.
- Caesium-137 (^{137}Cs) is relatively mobile, with a half-life of 3 x 10^{6} years.
- Cobalt-60 (^{60}Co) is relatively immobile, with a half-life of 5.27 years.

The modelling results indicate that the amount of solutes originating from the repository reaching the watertable under the conservative scenario of continual low level seepage for 100 years would be so low as to be, to all practical extent, undetectable. Even if 100% of rainfall and stormwater were to penetrate the repository, the modeling results indicate that the amount of solutes reaching the watertable would be less than 10^{-100} mg/L, that is, undetectable. The natural climatic regime of the study region, together with the design and construction of the repository, would provide considerable additional protection for the watertable.

Prediction of this modelling assessment is considered to be due, in large part, to the very low rates of downward percolation that occur under arid conditions, and the thick nature of the unsaturated zone. This allows time for decay of the radionuclides, greatly reducing their concentration before they reach the watertable.

The findings of the modelling correlate with research carried out elsewhere in Australia and the US, which concludes that in desert (arid) areas the dominant direction of water movement in soil is upwards. This upward movement is due to the low level of rainfall and high evaporation rates in these areas. While individual large rainfall events can generate a downward moving wetting front, the dry conditions that follow result in the vast majority of this moisture being drawn back to the surface through evaporation and capillary forces.

Consequently, transport of the nuclides may occur initially as advective (carried by moving water) flow with or behind the wetting front, but this eventually becomes dominated by transport by diffusion and dispersion as the geological profile dries. The dispersion and diffusion rates are generally much lower than the advective rates; hence, the rate of movement of the nuclides is greatly reduced, allowing time for decay to occur.

8.10.4 Radon Emanation

Radon (^{222}Rn) gas from the decay of radium-226 (^{226}Ra) in the waste would diffuse through the waste material and the cover. The concentration of radon in air at ground level would be governed by the radon exhalation rate or flux from the cover material, and by atmospheric dilution, which depends on the prevailing meteorological conditions.

Apart from the ^{226}Ra content of the waste, the resultant radon exhalation rate at the surface of the cover material is a consequence of a number of characteristics of the waste and cover, for example the moisture content, porosity, particle size of the soil, bulk density and thickness of the cover.

If the cover material does not contain significant levels of ^{226}Ra, the main governing parameter for the reduction factor for radon exhalation rate by the cover is the ratio of the cover thickness to the diffusion relaxation length for cover material. This latter parameter effectively is the distance a radon atom travels in the material before decaying. It is related to the radon decay rate (half-life) and the diffusion coefficient for radon in the cover material.

Therefore, the radon diffusion coefficient of the cover material is most important in determining the exhalation rate at the surface. There are significant differences in diffusion coefficients for various soil types. For example, the diffusion coefficient for clay is an order of magnitude less than that for silty sand. The presence of moisture also further reduces the diffusion coefficient, and clay materials have a greater capacity for moisture retention.

A 5 m cover without significant ^{226}Ra content would reduce the exhalation of radon into air by a factor of approximately 100. Attenuation of the surface radon flux from ^{226}Ra in the waste would be further aided by incorporation of a clay layer within the 5 m cover. It has been estimated that, for a 1 m clay layer within the 5 m cover, there is an attenuation factor of 450 for the radon flux at the surface compared to uncovered waste (NHMRC 1997).

8.11 Impacts, Risks and Safeguards During Surveillance, Decommissioning and Institutional Control

Potential impacts and proposed environmental safeguards associated surveillance of the site between disposal campaigns, decommissioning and the institutional control period of the project are presented below (Table 8.16).

TABLE 8.16 Potential environmental impacts and safeguards during surveillance, decommissioning and institutional control

Issue	Management strategy
Potential impact	
Pollution of surface water runoff and erosion	▪ Prepare a surveillance and rehabilitation management plan consistent with South Australian EPA policy ▪ Rehabilitate and revegetate access tracks and other disturbed areas after decommissioning ▪ Remove buildings and infrastructure, then rehabilitate and revegetate the site after decommissioning ▪ Ensure integrity of final cap through revegetation and establishment of appropriate slope grades ▪ Repair and revegetate depressions or erosion channels detected during monitoring according to the design standard
Pollution of groundwater	▪ Ensure the integrity of cap and slope grades are maintained ▪ Repair and revegetate depressions and erosion channels according to the design standard
Potential for release of pollutants to surface water	▪ Maintain natural drainage channels or levees to avoid flooding of site ▪ Maintain cap
Potential for release of pollutants to groundwater	▪ Maintain drainage, preventing ponding of surface water on or near trenches; maintain cap

8.12 Monitoring Programs and Procedures

The monitoring programs listed in Tables 8.17 and 8.18 are proposed to be undertaken as part of the project.

TABLE 8.17 Environmental monitoring requirements during construction and operation

Issue	Monitoring requirement
Physical environment	
Surface water runoff and erosion	■ Regular inspection of drainage lines for evidence of sediment transport (quarterly during periods without rain and ad hoc following any rain events) ■ Regular inspections of bunded areas to confirm integrity of bunds ■ Inspection and maintenance of erosion control measures ■ Clean-up of areas of accidental spillage of fuels and appropriate disposal of spilled material
Dust	■ Visual monitoring to determine areas of excessive dust generation and activities creating dust, to ensure that any dust arising is minimal
Noise	■ Measurement of noise levels during operation to ensure consistency with South Australian EPA Industrial Noise Policy and OH&S requirements
Potential for release of pollutants to soil	■ Ad hoc inspections following rain events ■ Ad hoc inspections following any fuel/oil spills and after clean-up activities ■ Ad hoc inspections following any received waste spills, with waste and affected soil rremoved/repackaged for disposal in trenches/boreholes
Potential for release of pollutants to surface water	■ Opportunistic sampling of flowing surface water upstream and downstream of site with analysis of salinity, turbidity / total suspended solids and selected radionuclides to build up background dataset ■ Ad hoc inspections following rain events ■ Ad hoc inspections following any fuel/oil/waste spills and after clean-up activities
Potential for release of pollutants to groundwater	■ Quarterly monitoring of water levels in all available drainage layers and groundwater monitoring wells ■ Ad hoc monitoring of sampling well in basal drainage layer of closed trenches after significant rainfall ■ Annual groundwater sampling for pH, electrical conductivity / salinity, major ions and selected radionuclides

TABLE 8.18 Environmental monitoring requirements during surveillance, decommissioning and institutional control

Issue	Monitoring requirement
Physical environment	
Surface water and erosion	■ Preparation of a surveillance and monitoring plan consistent with South Australian EPA policy ■ Surveillance (yearly or after significant storm events) to assess the integrity of the cap
Potential for soil erosion / siltation of water courses	■ Annual inspection, reducing to five-yearly after five years ■ Ad hoc inspections following major rain events (>500 mm/month)
Potential for release of pollutants to soil	■ Annual inspection, reducing to five-yearly after five years
Potential for release of pollutants to surface water	■ Annual inspection, reducing to five-yearly after five years ■ Ad hoc inspections following major rain events (>500 mm/month)

Issue	Monitoring requirement
Potential for release of pollutants to groundwater	▪ Annual monitoring of water levels in all available drainage layers and groundwater monitoring wells, reducing to five-yearly after five years ▪ Ad hoc monitoring of sampling well in basal drainage layer of closed trenches after major rainfall events (>500 mm/month) ▪ Annual groundwater sampling for pH, electrical conductivity / salinity, major ions and selected radionuclides, reducing to five-yearly after five years