4 Physical environment

This chapter describes aspects of the physical environment, including climate, landforms, and soils in and around the Project Area. The key issues addressed are erosion, sedimentation and potential changes to soil chemistry. Issues relating to surface waters and groundwater are covered in Chapter 5 and Chapter 6 respectively.

4.1 CLIMATE

The climate of the Project Area is typical of the Kimberley region, with two dominant seasons—a wet and a dry season. The wet (monsoon or cyclone) season usually extends from November to April, while the dry season can be taken as May to October. During the wet season, temperatures and rainfall are relatively high with much of the rain activity coming from thunderstorms and cyclones formed in subtropical low-pressure systems off the coast. In contrast, the dry season is characterised by lower temperatures, low rainfall and lower humidity.

The mean daily maximum temperature in Kununurra exceeds 37°C from October to December, after which temperatures decline slightly due to increased cloudiness and humidity (Figure 4.1). Average daily minimum temperatures reach 26°C in December and even in the coldest month, July, do not drop below 15°C.

The average annual rainfall at the Kimberley Research Station from 1946 to the present is 776 mm, with around 90% occurring during the wet season. In the extremely dry year of 1952, only 403 mm was recorded while in the wet year of 1959, 1,448 mm was recorded. Some showers may occur during May, June, July and October (60–100 mm have been recorded at least once in these months); however, August and September consistently have very low rainfall with a maximum recorded monthly total of some 30 mm. The variability of rainfall increases with latitude from north to south, with the lower Ord Valley (which is representative of the Project Area) experiencing relatively predictable rainfall.

Net evaporation rates are generally high, of the order of 2,100 mm/a. During most months, evaporation exceeds precipitation.

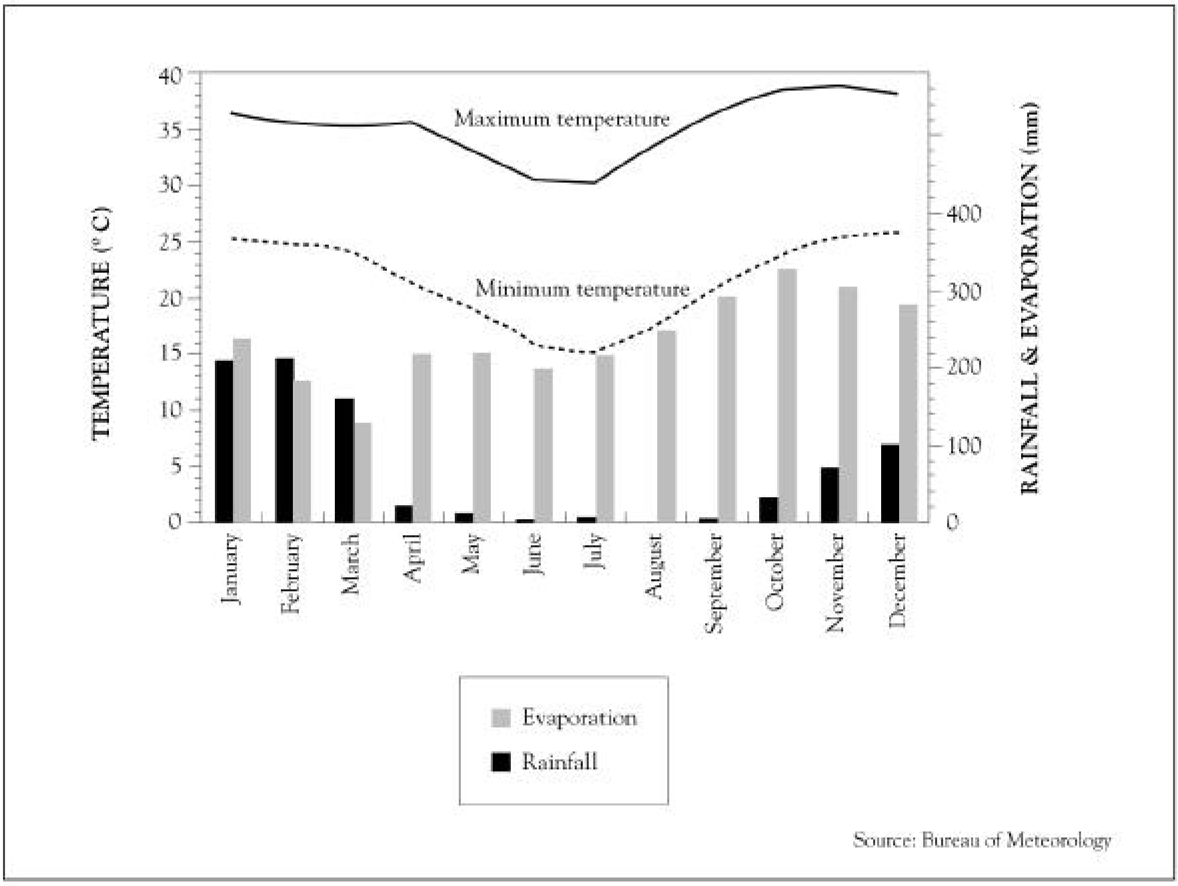


Figure 4.1 Average climatic data for Kununurra

4.2 GEOLOGY

The geology of the Kimberley is relatively complex, and is the principal determining factor for the form of the landscape. Detailed descriptions of the geology of the Ord River area can be found in Traves (1955), Dow and Gemuts (1969), and Mory and Beere (1985; 1988). From these accounts it is evident that the geology of the Project Area and its surrounds is dominated by a basement of sandstones, shales, limestones and conglomerates overlain by 5–25 m of alluvial sediments deposited by the Ord and Keep rivers.

The area that would be developed as part of the Project (Project Area) is confined to three fluvial plains: the Weaber Plain, the Keep River Plain and the Knox Creek Plain. The Weaber and Knox Creek plains form wide and generally flat valleys at an elevation of approximately 25 m Australian Height Datum (AHD). The Keep River Plain, located adjacent to the lower reaches of the Keep River, has an elevation varying from about 20 m AHD in the south-west to about 10 m AHD in the north-west.

The Weaber, Keep River and Knox Creek plains are characterised by little undulation in topography. Rivers and creeks incise the topography only locally and to a maximum depth of about 5 m. The plains contain occasional craggy breakaways of rock, for example, Folly Rock, which rises steeply within the Weaber Plain to approximately 140 m AHD. On the fringes of the river plains there is generally a very marginal rise in the topography due to the presence of aeolian sand deposits, with the most notable deposit occurring along the Pincombe Range.

The hills local to the Project Area are generally steep and rocky. They are largely devoid of vegetation and rise up to about 200 m above the level of the surrounding country. A steep pediment generally marks the transition from hill to plain and is present at the base of most of the hills.

Limestone and sandstone formations are of particular interest as karst systems or caves can develop in these materials. Such systems can potentially provide habitat for subterranean fauna. There are, however, no occurrences of limestone outcrops inside the area proposed for development. The nearest are as follows:

- A dolomite outcrop north-west of Folly Rock, located in conservation area within the Project Area (Chapter 10 refers).
- Inter-bedded sandy limestone outcrops occur at the foot of the Weaber Range; however, the beds are too thin and the sand content too high for cave development (Humphreys 1995). The foot of the Weaber Range approximates the northern extent of the Project Area on the Weaber Plain. The Project Area would contain undeveloped land surrounding that developed for farms, and this undeveloped land would be managed for conservation. The developed land would generally occur some 0.5–1 km south of the foot of the Weaber Range.
- South of the Project Area, the Cave Spring Range and the Pincombe Range consist mostly of inter-bedded sandstone and siltstone. While the former contains a well-known cave at Cave Spring, these ranges are generally not considered suitable for extensive cave formation (Humphreys 1995).
- Limestone formations in the Jeremiah Hills contain some significant cave systems, one at least with a horizontal extent of more than 10 km (Humphreys 1995). The Jeremiah Hills, however, are located well outside the Project Area, being some 4 km to the west.
- A small isolated limestone outcrop about 2 km long by 500 m wide occurs approximately 2 km north of the westernmost farm proposed for the Weaber Plain (shown as W21 in Figure 3.2). The proposed conservation buffer area surrounding the farmland is 1.5 km at this location, which places the limestone outcrop some 0.5 km outside the Project Area. This outcrop has not been surveyed for the presence of caves and associated fauna.

4.3 LANDFORMS

The regional land systems, including those of the Project Area, have been described by Stewart (1970) and are shown in Figure 4.2. The Project Area generally comprises fine-textured fluvial plains of the Ivanhoe Land System that are flat to gently undulating, with localised variation in topography and soil types. The Ivanhoe Land System has traditionally been the primary target for irrigation projects because of its relative uniformity, gentle slopes and suitable soils.

Surrounding the Project Area are the following landforms:

- the Cockatoo Land System, made up of gently undulating plains on sandstone and calcareous sandstone, or deep sands;
- rugged hilly country with ridges, hogbacks, cuestas and structural plateaux of the sandstone, calcareous sandstone and conglomerate rock outcrops of the Weaber Land System, or of the sandstone, siltstone and shale rock outcrops and skeletal soils of the Pinkerton Land System;

- gently sloping alluvium with leached yellowish loamy and sandy soils of the Angallari Land System and undulating plains on dolomite and shale, leached loamy soils with moderate limestone outcrop of the Dinnabung Land System;
- estuarine alluvium cracking clay and solonetzic soils of the Legune Land System;
- estuarine alluvial plains, saline soils and bare mud of the Carpentaria Land System.

4.4 SOILS

The distribution of Great Soil Groups, as defined by Stace et al. 1968, within Land Systems found within or close to the Project Area is given in Table 4.1.

Table 4.1 General soil profiles and Great Soil Groups in Land Systems within or close to the Project Area

General soil profile	Great Soil Group	Occurrence in Land System							
		Pi	W	Cc	D	Ag	Iv	Lg	C
Leached gradational soils	Red earth (sandy)		m	D		m	m		
	Red earth (loamy)	m		m	S	m	m		
	Yellow earth (sandy)		m	S		S			
	Yellow earth (loamy)	m			D	D			
	Lateritic podzolic								
	Meadow podzolic					m			
	Acid swamp								
Cracking clay soils	Grey and brown heavy texture				m		D	S	m
Texture contrast soils	Red-brown earths								
	Solonetzic			m		m			m
Calcareous soils	Rendzina				m				
	Grey and brown calcareous				m				
Undifferentiated	Skeletal	D	D	m	S				
	Alluvial	m					m		
	Solonchak							m	D
	Aeolian								m

Legend: D=dominant, S=subdominant, m=minor.

Pi=Pinkerton, W=Weaber, Cc=Cockatoo, D=Dinabung, Ag=Angallari, Iv=Ivanhoe, Lg=Legune, C=Carpentaria.

Source: Stewart et al 1970

Soil surveys within the Project Area have been undertaken by Aldrick and Moody (1977), Dixon (1996), Schoknecht and Grose (1996) and Schoknecht (1998). These have shown that cracking clay soils, known as Cununurra and Aquitaine clays, are dominant within the Project Area. Smaller areas of red-brown earths, red earths, brownish cracking clays, colluvial outwash slopes, rock outcrops and other soils also occur. The distribution of these soils is shown in Figure 4.3.

Cracking clay soils are common on the Australian continent, with major occurrences in the Northern Territory, western Queensland and New South Wales. However, they are uncommon in Western Australia, with relatively small areas present in isolated areas in the northern parts of the State (Hubble et al. 1983).

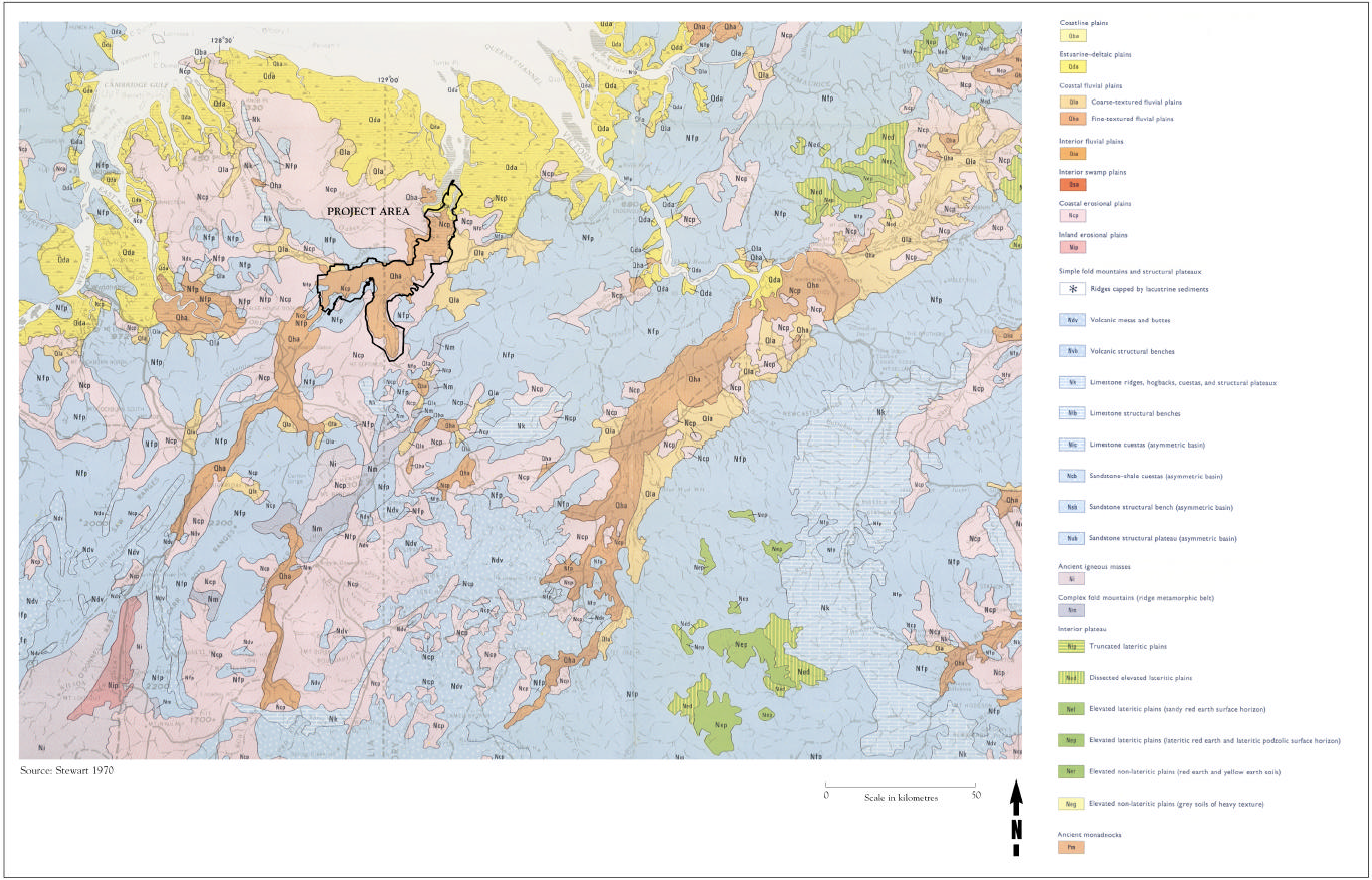


Figure 4.2 Land Systems surrounding the Project Area

Cracking clay soils are often described as black soils or vertisols. They exhibit significant shrinking and swelling properties resulting in deep, open desiccation cracks into which vegetation will often fall. This then becomes incorporated into the soil mass, giving the dark grey or black colouration. Continuous movement due to moisture variations can result in slickensides or polished surfaces within the soil profile. The extreme shrinking and swelling can also result in *gilgai* or melonhole structures, giving the local topography a slight undulation.

Black soils are commonly associated with deep weathering of underlying calcareous or basic rocks. However, there are a number of factors that suggest that the black soils within the Weaber, Keep and Knox Creek plains may be transported soils. These factors include the presence of alluvial materials (clays, clayey sand and sand) immediately underlying the black soils, the apparent absence of basic bedrock geology in the area, and the general absence of any substantial amount of silica, which would be present if the soils were the weathering product of sandstones and siltstones. Crystals of gypsum, believed to have precipitated post-deposition, are also present in the black soils of the Project Area.

A summary of the soil's physical and chemical characteristics from a selection of representative Cununurra and Aquitaine clays within the Project Area is presented in Table 4.2 (guidelines for cropping are shown in Table 4.3). Of interest is the soil pH, which is generally in excess of 7, which indicates that alkaline soils are typical of the Project Area. Acid sulfate soils are not known to occur in the vicinity of the Project Area. The soil types found in the Project Area are described further below.

Table 4.2 Selection of soil's physical and chemical properties within the Project Area

Soil	Depth	Range	Electrical conductivity* (mS/m)	pH*	Nitrogen (% < 2 mm)	PhosphorusH (ppm)	Organic carbon (% < 2 mm)
Weaber Plain							
Aquitaine clay	Surface	min.	7	6.6	0.02	58	0.23
		max.	58	8.0	0.05	150	0.74
	150 cm	min.	16	8.2	0.01	51	0.13
		max.	159	9.2	0.02	91	0.27
Cununurra clay	Surface	min.	8	7.4	0.04	59	0.52
		max.	8	8.2	0.04	74	0.54
	150 cm	min.	72	9.0	0.02	62	0.28
		max.	115	9.4	0.02	160	0.39
Knox Creek Plain							
Cununurra clay	Surface	min.	10	6.7	0.03	53	0.44
		max.	64	7.1	0.05	98	0.90
	150 cm	min.	58	7.8	0.01	40	0.01
		max.	480	8.8	0.01	100	0.09
Keep River Plain							
Cununurra clay	Surface	min.	7	6.6	0.02	–	0.43
		max.	27	8.1	0.07	–	1.01
	150 cm	min.	68	8.0	–	–	–
		max.	1163	9.0	–	–	–

* *In mixture of one part soil and five parts water.*

H *Leached with 6M HCl.*

– *Indicates data not available*

Sources: Dixon 1996; Schoknecht and Grose 1996; Department of Industries and Development 1977.

Table 4.3 Guidelines for cropping

Soil property	Guidelines
Electrical conductivity (mS/m)	If > 200 in surface soil, 10% yield decline (Hunsigi 1993).
pH	Range of 6–7.5 preferred (Baker and Eldershaw 1993).
Nitrogen (% < 2 mm)	Preference for optimal crop growth is > 0.15 (Baker and Eldershaw 1993).
Phosporus (ppm)	Preference for optimal crop growth is > 36 (Baker and Eldershaw 1993).
Organic carbon (% < 2 mm)	Preference for optimal crop growth is > 1.5 (Baker and Eldershaw 1993).

Cununurra clay

A typical profile of Cunnunurra clay consists of a 50 mm loose, self-mulching surface layer overlying 1.2–1.4 m of strongly structured, very hard, medium to heavy clay. Below this depth the clay grades into reddish parent alluvium. Shrinkage cracks generally penetrate to approximately 200 mm. A number of distinct phases or variants occur for the Cununurra clays including ‘normal’, ‘leached’, ‘eroded’, ‘brown’, ‘darker’ and ‘flooded’ (Schoknecht and Grose 1996). These vary in both drainage characteristics and soil chemistry.

Electrical conductivities are very high in subsoils below Cununurra clays on the Knox Creek Plain and in places on the Keep River Plain (480–1,163 mS/m). There is a strong possibility of soil salting if the groundwater is allowed to rise and, consequently, it is proposed that control be exercised over water application and that this be combined with groundwater monitoring and management.

Aquitaine clay

Aquitaine clay is also a cracking clay soil, but it is generally found in flatter, lower lying areas than in the Cununurra clay. Aquitaine clay occurs over much of the western and north-western parts of the Weaber Plain and portions of the southern and eastern margin of the Keep River Plain.

Aquitaine clay areas are subject to more frequent, prolonged inundation and generally have a higher clay content than Cununurra clays. They also exhibit a weaker self-mulching behaviour, and have a coarser underlying structure. The subsoil below about 1.3 m is yellowish to brownish with some mottling.

Aquitaine clays can be more susceptible to drainage problems and salinisation than Cununurra clays due to their lower permeability (Riley et al. 1993). However, the major occurrences of Aquitaine clays in the Project Area are on the Weaber Plain, and on this plain the Aquitaine clays appear to have salinity and sodicity characteristics similar to those of Cununurra clays.

Other soils

Other than Cununurra and Aquitaine clay soils, a range of other soils can be found on the Weaber, Keep River and Knox Creek plains. These include red-brown earths (Weaber and Bonaparte), solodic red-brown earths (Bentons) and small rocky outcrops. Small areas of Cockatoo sands also occur on the south-west periphery Knox Creek Plain.

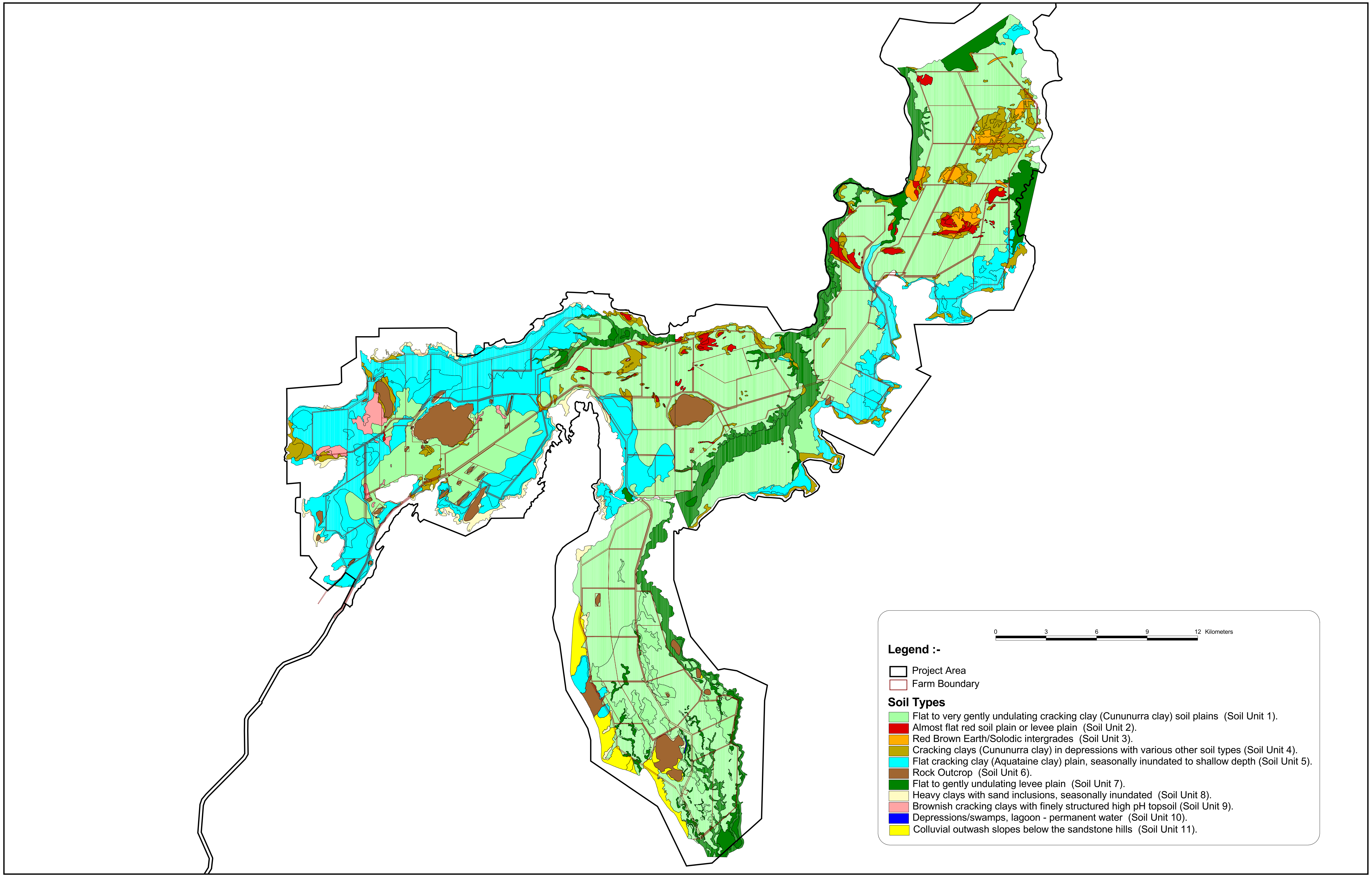


Figure 4.3 Soils of the Project Area

Sand, silt and gravel are present in areas of very limited extent, and are principally confined to incised drainage channels. At a number of creeks, particularly in the Knox Creek Plain, there is a thin cover of alluvium extending beyond the channel, indicating periodic high-energy overbank discharge.

Poorly drained and highly variable soils, generally heavy clays with sand inclusions, occur around the margins of the Weaber Plain, on the eastern boundary of the Ivanhoe Plain and surrounding rocky outcrops in the Knox Creek and Weaber plains. These soils are located outside the proposed farm development area.

4.5 PREDICTED IMPACTS AND THEIR MANAGEMENT

The Project would not affect the climate or geology of the area; however, some impacts on landform and soils may occur. These potential impacts, and the manner in which they would be managed, are described below. Management and monitoring measures proposed are described further in the outline Environmental Management Plan provided as Appendix O.

4.5.1 Landform

The landforms within the Project Area would be modified from the existing primarily natural state to become a highly managed agricultural landscape. The drainage patterns of the plains would be modified to provide a more consistent gradient and to facilitate optimum water application and drainage. In addition, a formal drainage system would be developed within and around the Project Area.

4.5.2 Erosion

Soil erosion in the Project Area would be controlled by a combination of the following management strategies:

- controlling drainage by providing levee banks to prevent floodwaters entering the developed area;
- grading land on farms to gentle slopes to minimise stormwater runoff velocities;
- sizing and designing receiving drains to accommodate anticipated flow regimes;
- providing buffer zones on both sides of watercourses to allow riparian vegetation to continue to stabilise soils in these areas;
- rehabilitating disturbed areas:
  - as soon as possible following disturbance during construction;
  - by formulating and implementing appropriate rehabilitation plans and programmes including topsoil stripping and stockpiling, land preparation, and reseeding with local, native species to facilitate regeneration of disturbed areas;
- managing crops in such a way that crop cover of the soil is maximised, particularly during the wet season when erosive rainfall events may occur.

Monitoring and remediation of erosion would also occur as part of normal operations within the Project Area.

4.5.3 Sedimentation

In their natural state, regional rivers carry high silt loads without showing significant signs of sedimentation in their lower reaches. This factor is due to a combination of the fine-grained nature of the silt load and the high-energy environments within the rivers during wet season flows.

Drainage waters leaving farms would first pass through farm drains and tailwater return systems that would settle and collect larger soil particles, such as coarse silts and sands. The remaining silt load would be similar to that in the regional rivers, and thus sedimentation of downstream watercourses is not expected to occur. Farm maintenance would include regular desilting of these drains and the return of the collected material to the cropped area.

4.5.4 Soil chemical status

The application of water and fertiliser may impact on the natural physical and chemical status of the soil. Such impacts may include:

- increased levels of salt and sodium ions (sodicity) specifically associated with irrigation;
- an increase in soil-available-nutrient status resulting from the application of fertiliser and from natural nitrogen fixation from leguminous crops;
- long-term changes in the overall balance of macro- and micronutrients in the soil reflecting the cropping and fertiliser regimes.

A review carried out in ORIA Stage 1 by Lavelle (1983) concluded that salinity and sodicity were not a problem at that time. However, Lavalle noted a high relative bicarbonate concentration (110 mg/L) in the irrigation water and preferential precipitation of calcium on to the soil and release of sodium. This created a potential hazard to irrigation, particularly for the cracking clays, which have a high susceptibility to sodium damage.

The extent of the sodicity hazard was further investigated by the Department of Agriculture (George 1983, unpublished). Profile cores were taken from eighteen farms with irrigation histories of from two to twenty-three years, but with most being around sixteen years. Cores were also taken from three virgin sites. The results are displayed in Table 4.4. The main findings may be summarised as follows:

- Soil salinities were universally low and safe for plant growth. There was a tendency for soluble salts to increase with depth, the main increase being below about 1 m.
- The exchangeable sodium percentage (ESP) levels of Cununurra clay are low (< 3) at the surface but increase with depth to values of 10–20. Virgin Aquitaine clay has higher ESPs of 4–6 at the surface, increasing to 27 at depths between 1.2 m and 1.5 m. These levels are quickly reduced under irrigation.
- Soil pH levels are high, reflecting the presence of free calcium carbonate in most horizons. Where the pH is greater than 9.1, the ESP is usually greater than 10–12.
- The increase in ESP with depth is caused by the precipitation of the calcium carbonate derived from the irrigation water as its concentration is increased by water uptake by the crop.

Table 4.4 Soil salinity (EC_e) and ESP levels under various blocks in ORIA Stage 1

		Depth 0–0.3 m		Depth 1.2–1.5 m		
Block	Soil type	EC_e (mS/m)	ESP	EC_e (mS/m)	ESP	Years of cropping
36/9	C	56.2	1.4	56.3	11.4	16
36/10	C	43.3	1.5	56.7	10.8	16
36/11	C	51.0	1.4	63.2	12.0	16
36/12	C	43.5	1.6	94.1	14.7	16
63/2	C	65.3	0.4	106	10.4	14
63/4	C	36.7	2.6	272	14.8	18
38	W	57.1	2.5	277	24.3	14
75	A	49.2	3.8	241	14.5	15
113	A	34.3	1.5	104	9.5	2
KRS/1A	C	54.4	1.4	80.4	11.4	18
KRS/4A	C	46.1	2.5	76.4	20.6	23
46	C	24.8	0.7	53.0	12.5	19
54	C	18.8	0.2	35.9	3.7	19
72	C	26.1	0.1	40.1	2.7	15
89	C	64.5	3.3	481	20.7	18
97	C	40.6	2.0	298	20.3	17
106	C	38.7	2.8	279	17.8	7
28	C	–	3.4	–	20.3	18
87	C	19.7	1.2	382	13.9	Virgin
68	A	51.4	7.8	576	27.0	Virgin
68	T	60.6	5.2	1040	18.7	Virgin

Legend: C = Cununurra clay, A = Aquitaine clay, W = Walyara, T = transitional (Cununurra to Aquitaine).
EC_e = electrical conductivity of saturation extract.

Source: George 1983 (unpublished).

George's results confirm work carried out earlier by Aldrick et al. (1978), which found that ESPs at depths of below 0.6 m increased with as little as two irrigations (see Table 4.5). Relative stability in the values resulting from irrigation was also achieved.

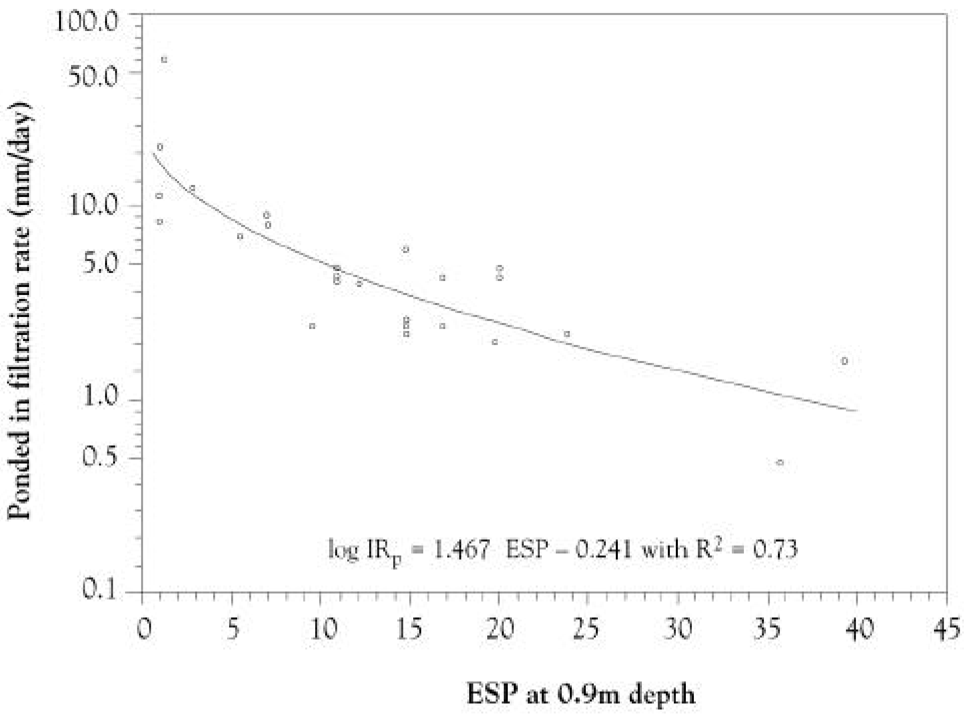
ESP levels above 6 cause soil dispersion and a lowering of hydraulic conductivity. Dispersion tests carried out on the samples confirmed that, at below an ESP level of 6, none of the samples were dispersive, while above an ESP level of 16 virtually all of them were dispersive.

Table 4.5 Effect of cropping history on ESPs of Cununurra clay

Depth (cm)	Inundated crops			Furrow-irrigated crops			
	Virgin	**Two rice crops**	**Four rice crops**	**Virgin**	**Two crops**	**Three crops**	**Seven crops**
0–30	1	1		1	2	2	2
30–60	3	4	4	2	6	5	4
60–90	7	10	7	6	12	10	9
90–120	10	16	10	8	17	15	14
120–150	12	19	13	10	19	17	17
150–180	13	20	14	10	19	19	19

Source: Aldrick at al 1978.

Considerable work on sodicity has been carried out in Queensland and a relationship between ponded infiltration rates and ESP at 0.9 m depth has been established for soils in the Emerald area (Shaw and Yule 1978). This relationship, shown in Figure 4.4, confirms the relationship between increasing dispersion (and hence lower hydraulic conductivity and infiltration) with higher ESP. Shaw (1988) also reports that an ESP of 15 can be tolerated at subsoil depths, particularly if the soil is a cracking clay. Based on the Queensland experience, a target ESP of 15 at 1.3–1.5 m depth has been adopted for the Project.



Source: Shaw and Tule 1978; Gardner and Coughan 1982

Figure 4.4 Relationship between Ponded Infiltration Rate and ESP

The ESP profiles shown in Table 4.4 also include those for two blocks of the sugar pilot farm in ORIA Stage 1, where various irrigation techniques were trialled as follows:

- Block 63/2 was flood irrigated and had a leaching factor in the range of 0.07–0.11. (The leaching factor is the proportion of applied water, including rainfall, that passes the root zone of the crop.) The ESPs on Block 63/2 were all reduced below that of the virgin soil, and the ESP at 1.2–1.5 m was 10.4 and therefore below the limit of 15 adopted for the Project.
- Block 63/4 was furrow irrigated and had a leaching factor in the range of 0.03–0.04. The ESPs on Block 63/4 were all slightly above the virgin state and the ESP at 1.2–1.5 m was 14.8, at approximately the acceptable limit adopted for the Project.

Sodicity issues would be managed indirectly through management of irrigation practices. Numerical modelling of accessions to groundwater, described in Appendix H, has shown that the irrigation practices proposed for the Project would result in leaching rates past the crop root within the range 56-119 mm/a, with 94 mm/a being the predicted rate for average soil and meteorological conditions. A leaching rate of 94 mm/a corresponds to a leaching factor of about 0.04. Based on the above data it would appear that this leaching factor of 0.04 would be acceptable as it would maintain subsoil ESPs around the virgin levels and below 15.

Long-term monitoring would be undertaken to ascertain any changes to surface and subsoil salinity and sodicity resulting from the proposed irrigation practices, for example by assessing sodium adsorption ratio, ESP and electrical conductivity levels. Alternative management measures would be investigated and trialled if the monitoring should detect an increase in subsoil sodicity levels sufficient to threaten the long-term sustainability of the Project. These management measures could include:

- the application of gypsum to either the cropped area or the irrigation water;
- the blending of groundwater with irrigation water to increase the salinity of the water applied to the cropped area;
- a change in irrigation practices, to result in a greater leaching factor than that proposed at the present time.

The first two of the above management methods would result in a beneficial change in irrigation water chemistry with respect to the control of sodicity. The third method would result in a greater rate of seepage to groundwater, and a potential requirement to bring forward and increase the groundwater management measures proposed for the Project as described in Chapter 6. The converse scenario is also a possibility in that monitoring may indicate that a lower leaching fraction to that currently proposed may be acceptable to control salinity and sodicity. In this case, the irrigation practices would be modified to reduce the accessions to groundwater, thereby conserving water and reducing or postponing the Project's groundwater management requirements.

Within the irrigation area, the chemical status of the soil would also be routinely assessed as a component of ongoing management. This would include regular assessment of soil chemistry, including macro- and micronutrient status, organic matter content and pH. Records of soil tests would be maintained to develop a history of soil chemical and physical status.