6 Groundwater

This chapter addresses groundwater issues associated with the Project. It describes the features of the regional geology and existing groundwater environment (hydrogeology) together with measures proposed to manage impacts on a sustainable basis. Extensive numerical modelling was used to develop the groundwater management strategy for the Project and to quantify the range of likely impacts. This modelling is also described, with reference to technical appendices where appropriate.

6.1 BACKGROUND

The groundwater environment beneath the Project Area is currently considered to be in equilibrium, with groundwater levels reflecting a balance between geological formation and recharge from the surface. Development of the Project Area for broad-acre flood irrigation would change the hydrological cycles on the land surface of the Project Area. This would result in a change in the rate of groundwater recharge and, hence, a change in groundwater levels.

Currently the land surface is dry for approximately seven to eight months of the year during the dry season; this results in extensive cracking of the surface soils. During the following wet season, the black soils absorb water and expand, closing the cracks and thereby establishing a relatively impermeable surface layer. At this time the black-soil plains of the Project Area are characterised by free water on the surface due to a combination of intensive rainfall, poor drainage and the low rate of infiltration of water into the ground.

Net evaporation rates are high in the region, averaging about 2,100 mm/a, far in excess of the average rainfall of 776 mm/a. Tree coverage on the black-soil plains is extremely limited; however, a dense coverage of native grasses (see Chapter 8) quickly establishes itself during the wet season and, through evapotranspiration, these grasses add considerably to the rate of soil moisture loss. Although limited, the available evidence suggests that the rate of soil moisture loss is sufficient to result in the black-soil plains currently contributing little or no recharge to underground aquifers.

As mentioned earlier, the development of the black-soil plains for broad-acre flood-irrigated agriculture would change the hydrological cycles on the land surface. It would do this in a number of ways, as outlined below:

- Irrigation water would be applied to the land surface during the dry season, and occasionally during dry periods in the wet season, with the rate of application managed to satisfy the evapotranspiration rate of the crop.
- Drainage infrastructure construction and grading of the farm units would provide an efficient means of stormwater removal.

- Irrigation channels and balancing storage dams would be constructed that would be permanently filled with water.
- The native vegetation cover would be replaced with perennial crops, predominately sugarcane.

The above changes are expected to result in an increased rate of water infiltration (known as accessions) to underlying aquifers and a consequential rise in groundwater levels. The rate of groundwater rise and the need for groundwater management measures would vary with a number of factors, including the magnitude of the accessions to groundwater, the initial depth of groundwater from the surface, and local hydrogeological features. Agricultural activities are generally not affected unless groundwater levels are within approximately 2 m of the surface, a condition referred to as waterlogging. However, management measures are generally required for groundwater within 5 m of the surface, particularly if the groundwater is saline or the rate of groundwater rise is sufficient to cause waterlogging in a short timeframe.

The following sections describe the existing local groundwater environment, changes predicted as a result of the proposed development proceeding, and how groundwater would be managed to enable long-term use of the Project Area for irrigated agriculture.

6.2 REGIONAL GEOLOGY

The regional geology of the Project Area has been described by Moray and Beere (1988). Geological descriptions of portions of the area are presented in Laws (1991), Sweet et al. (1974) and Whitehead and Fahey (1985). The Water and Rivers Commission and the Department of Lands, Planning and Environment have also compiled an interpretation of the geology and hydrogeology of the ORIA. An extract of this interpretation covering the Project Area is provided in (Appendix I). The following sections describe elements of the regional geology of relevance to the Project.

6.2.1 Basement geology

Weaber Plain

The Weaber Plain is bounded by outcropping basement rock to the north (Weaber Range) and the south (Pincombe Range and Sorby Hills). In the south-west, the plain is bounded by basement rock, with the exception of the Cave Spring Gap region.

Underlying most of the plain is a mixture of Precambrian to Permian units of varying lithology, including sandstone, limestone, shale and conglomerate. Through Cave Spring Gap, the basement rocks consist of Precambrian sandstone and shale of the Bastion Group. A major basement inlier within the plain, Folly Rock, is composed of Proterozoic sandstones of the Carr Boyd Group. North of Folly Rock, the basement changes to Carboniferous Milligan Formation shale.

In general, Palaeozoic sediments underlie the alluvial sequence through the northern portion of the plain while in the south, the basement is a thin sequence of Devonian limestone and sandstone overlying Cambrian Antrim Plateau Volcanics.

Knox Creek Plain

The geological strike along the Knox Creek Plain is dominantly north–south, consistent with the major axis of the plain. The plain is largely underlain by the Milligan Formation shale, incised by a palaeochannel and locally overlain by calcrete. To the west and north, the basement units underlying the plain include the Carboniferous Burt Range Formation, Septimus limestone, and well-bedded limestone and sandstone of the Devonian-Carboniferous Button Beds. Other units of the Landfield Group may be present. To the east, the plain is underlain by undifferentiated Permo-Carboniferous sandstone.

Knox Creek is generally fully contained within alluvial sediments and does not incise into the basement, except for an area of limited extent in the north.

Keep River Plain

The basement rock underlying the Keep River Plain is, for the most part, undifferentiated Permo-Carboniferous sandstone, with the exception of the southern portion of the plain, where the basement comprises Carboniferous shale. Alluvial sediments have incised into, and been deposited upon, both of these units.

6.2.2 Alluvial sediments

Weaber Plain

Alluvial sediments comprise the upper 5–35 m of the Weaber Plain (Nixon 1997b, 1997e). These sediments are presumed to have been deposited by the Ord River, when it is postulated to have flowed to the north-east beneath the Weaber Plain and then roughly along the course of the present-day Keep River. The sequence of sediments includes a basal coarse-grained unit (palaeochannel) deposited by the main river channel. Despite being restricted to a narrow extent through the plain these palaeochannel sediments are of considerable importance to the hydrogeology. The alluvial sequence becomes progressively finer upwards across the entire plain. However, little is known in detail of the variability of these sediments as the drilling that has been undertaken is sparse in relation to the area being considered and there is little correlation between boreholes for coarser or finer units (Nixon 1997a, 1997b, 1997d, 1997e).

Knox Creek Plain

The alluvial deposition within the Knox Creek Plain differs in part from that in the Weaber Plain by the poorer definition of the palaeochannel (although the palaeochannel is continuous beneath the eastern side of the plain) and the finer nature of the sediments. The alluvial sediments in the paleochannel become progressively deeper and broader in the northern part of the plain. A fining upward sequence is postulated, with the basal part of the sequence being finer than that of the Weaber Plain.

Calcrete is found beneath the western part of the Knox Creek Plain overlying the palaeochannel sediments or directly upon the basement complex. The calcrete varies greatly in width and thickness, to as much as 4 km wide and 15 m thick.

Keep River Plain

It has been postulated that the ancient course of the Ord River passed through the Weaber Plain and into the Keep River Plain. This river incised a deep channel, which has subsequently been infilled with the Tertiary and Quaternary sediments to form a palaeochannel. In the west, the palaeochannel is up to 35 m deep, with a coarse basal unit approximately 10 m thick. This is the downstream continuation of the palaeochannel as described for the Weaber Plain. Above the coarse palaeochannel sediments is a finer sequence with clayey sand at the base, fining upwards to a silty clay near the surface. Drilling by the Power and Water Authority has delineated the palaeochannel extent and thickness (Humphreys et al. 1995).

6.3 REGIONAL HYDROGEOLOGY

6.3.1 Groundwater flow

Weaber Plain

The general flow gradient beneath the Weaber Plain is from the west to the east (Appendix I). Elevated groundwater levels exist in the Cave Spring Gap as a result of the existing irrigation activities in ORIA Stage 1. The groundwater elevation just east of the current irrigation area is around 22–26 m AHD, which is around 5 m below the ground surface. From here groundwater flow is through the Cave Spring Gap and on to the Weaber Plain. The elevation of the water-table decreases to between 5m AHD and 10 m AHD in the vicinity of Folly Rock. This is some 20 m below surface, but may be up to 35 m below ground in some areas. In the north of the plain, near Point Spring, the groundwater elevation is higher than on the central part of the plain. A groundwater elevation at around 17 m AHD has been recorded (Nixon 1997a, 1997e), and it has been postulated that the broad areas of sandy soils in the Border Creek region (north of the Weaber Plain) are contributing some recharge to the sediments underlying the plain. This is also an area of relatively shallow bedrock, which may be contributing to the higher groundwater levels. The water-table associated with Point Spring occurs within the bedrock system and is entirely separated from the alluvial sediments.

East of Folly Rock, the groundwater level is at around 5 m AHD and remains above 3 m AHD to the eastern end of the plain. This is approximately 15–20 m below the general level of the plain. The incised valley of the Keep River is at approximately 12–14 m AHD, approximately 10 m above the groundwater level. There is no evidence of groundwater interaction with the river in this area, although data are poor. Groundwater recharge across the plain is considered to be very low. The existing groundwater gradient appears to be largely controlled by the palaeochannel throughflow from the Ivanhoe Plain and by recharge from the Border Creek area.

In the southern part of the plain, near Sorby Hills, extensive drilling for mining exploration has shown the basement rocks in this area to be limestone and dolomite, which have significant groundwater storage potential. . It has been assumed that there is little, if any, upward movement of groundwater from the basement rocks into the alluvial sequence. It is more likely that groundwater in this area moves from the alluvial sediments into the bedrock.

Knox Creek Plain

Groundwater flow beneath the Knox Creek Plain (Appendix I) appears to be to the north, following the paleochannel beneath the eastern portion of the plain. In the southern part of the Knox Creek Plain the groundwater levels are significantly higher than those in the northern part of the plain, by some 8 m. Groundwater flow in the southern section of the plain is to the north-west, from the Northern Territory section to Western Australia. Groundwater levels range from around 7 m AHD down to 3–4 m AHD where the Knox Creek Plain joins the Weaber Plain. This is approximately 10–15 m below the ground surface.

Recent drilling undertaken for the Project has shown that Milligan Lagoon is a localised perched aquifer formed by a clay layer that occurs to a depth of up to at least 9 m below ground. The regional water-table is some 20 m below the level of the lagoon. The lagoon is fed by rainfall and runoff, and possibly by minor groundwater inflow from the hills to the west.

Knox Creek and its tributaries are not considered to be part of the groundwater system as their bed levels are some 10 m above the current groundwater level. However, it is likely that these creeks are important groundwater recharge features during the wet season due to the general sandy nature of their bed profiles.

Keep River Plain

Groundwater flow beneath the Keep River Plain (Appendix I) is a continuation of the flow coming from the Weaber Plain, with groundwater elevations in the west of the Keep River Plain at or around the level of those in the Weaber Plain. Groundwater flow is then generally to the north-east, along the line of the plain with a smaller component to the north west, from the higher Permo-Carbonferious sandstone towards the alluvium.

The Keep River and Sandy Creek are in connection with the alluvial sediments along their length and, where these are tidal or semi-tidal, they provide a natural tidal control on groundwater levels. Beneath the Keep River Plain the basement rocks are in part Permo-Carboniferous sandstone, which is highly permeable and contains good quality groundwater. In the eastern end of the plain it appears that the permeable Permo-Carboniferous sandstone and the incised palaeochannel sediments comprise a single hydrological unit, although the nature, extent and degree of connection between the two systems have yet to be confirmed.

6.3.2 Groundwater quality

Regional groundwater quality, as mapped by the Water and Rivers Commission and the Department of Lands, Planning and Environment, is shown in Appendix I and described further below.

Weaber Plain

Groundwater quality beneath the Weaber Plain is generally fresh to slightly brackish (Nixon 1997a, 1997b, 1997e). Groundwater beneath the Cave Spring Gap appears to be fresh, around 1,000 mg/L TDS (Nixon 1997d). It is not clear if this level of salinity is influenced by accessions from current irrigation in ORIA Stage 1. Throughout the southern and central parts of the Weaber Plain, groundwater salinity ranges from 70 mg/L TDS to 2,600 mg/L TDS. At the northern edge of the plain the groundwater salinity appears to be associated with bedrock highs, although water analyses from Point Spring (Nixon 1997e) indicate that the groundwater emanating from bedrock in that region is of relatively good quality (50 mg/L TDS).

Knox Creek Plain

In the Knox Creek Plain the groundwater salinity ranges from 60 mg/L TDS to 20,800 mg/L TDS but in general is around 1,000 mg/L. The salinity is a sodium chloride type with elevated sulphate and bicarbonate.

Based on airborne electromagnetic studies conducted jointly by the Western Australian and Northern Territory Governments, there is considered to be a significant difference in the groundwater quality in the west of the plain compared with that in the east, reflecting the nature of the bedrock. Where alluvial sediments overlie the Milligan Formation shale the groundwater appears to be more saline than the groundwater overlying the permo-carboniferous sandstone. Delineation of the contact between these units and the potential impact on groundwater quality are discussed in Chin et al. 1997.

Keep River Plain

The groundwater salinity beneath the Keep River Plain varies greatly, ranging between 100 mg/L TDS and 51,000 mg/L TDS across the plain (Humphreys et al. 1995). The Department of Lands, Planning and Environment has identified six main salinity zones, based on airborne electromagnetic surveys and inferred basement geology. From west to east across the plain, the groundwater salinity changes from moderate to high (up to 20,000 mg/L TDS) adjacent to the tidal reaches of the Keep River, through a low salinity region (salinity expected to be less than 2,000 mg/L TDS) and then into a more saline region, which is within the influence of the tidal reaches of Sandy Creek.

The groundwater chemistry is dominated by sodium chloride ions, although bicarbonate concentrations are also commonly high. Nitrate levels are generally below 1–2 mg/L.

6.4 MANAGEMENT OF ACCESSIONS TO GROUNDWATER

6.4.1 Infrastructure

Irrigation and drainage infrastructure, as required by the Project, would contribute accessions to groundwater to varying degrees.

The irrigation water supply infrastructure, comprising main and secondary supply channels and balancing storage dams, would be permanently filled with water whereas the drainage water collection channels would only convey water intermittantly, predominately following rainfall. Accordingly, the methods of managing accessions to groundwater from this infrastructure would vary as outlined below:

- Irrigation channels would be constructed with a low permeability clay lining so that the rate of infiltration from the channel would be less than 2 mm/d. The clay lining would consist of compacted *in situ* clay where the *in situ* material is considered appropriate, or otherwise of compacted clay sourced from nearby borrow pits or other excavations necessary for infrastructure construction. Construction standards would be monitored to ensure that material selection and compaction standards are sufficient to restrict the maximum infiltration rate to the standard nominated above.

- Balancing storage dams would be sited in areas where the dominant surface soils are of Aquitaine clay. Aquitaine clay is the least permeable soil type occurring in the Project Area. As with the irrigation channels, construction standards would be monitored to ensure that the rate of infiltration is less than 2 mm/d from these balancing storage dams.
- Drainage channels would be designed to be broad and shallow to take advantage of the naturally occurring soil conditions; these consist of lower permeability clays nearer the surface, overlying soils of increasing permeability with depth. Sections of channels that traverse highly permeable soils would be modified to incorporate a lining of compacted clay.

The above measures represent current best-practice construction standards for irrigation infrastructure, and modern quality assurance procedures would be adopted during construction to ensure that the design intent is achieved in practice. As a minimum, these procedures would include extensive testing of soil properties to guide material selection and *in situ* testing of compaction levels prior to the works being accepted as complete. Soil type and degree of compaction are the main factors that determine a soil's capacity to minimise the infiltration of water.

6.4.2 Cropping areas

Sugarcane has a relatively high irrigation water requirement. Nearly all of this demand is needed to offset crop evapotranspiration, and irrigation schedules developed to satisfy this requirement only would eliminate accessions to groundwater. However, as described below, there are a number of reasons why it is neither practical nor desirable to eliminate all accessions to groundwater.

Some accessions to groundwater would be required to remove salts from the root zone of the crop that would otherwise accumulate from the consistent application of irrigation water, even from the low-salinity (160 mg/L TDS) water sourced from Lake Kununurra.

Also, as described in Chapter 4, some leaching of water through the soil profile would be desirable as a means of managing potential sodicity effects with the soils of the Project Area. Sodicity is a complex chemical reaction involving the exchange of sodium and calcium ions. In extreme cases sodicity can lead to precipitation of salts in soil voids, loss of soil structure and loss of agricultural viability. Maintaining a modest leaching fraction (up to 100 mm/a) is expected to mitigate the potential for sodicity effects.

Another factor that would influence accessions to groundwater is rainfall, particularly during the wet season. In the natural situation the onset of the wet season follows a long dry period that invariably leaves the upper soil profile dry. This situation would change following project development as the cropped areas would be irrigated during the dry season and the soils at the onset of the wet season would be in a moist condition. It is likely that rainfall during the wet season would be available immediately to infiltrate the soil profile, with the quantity of infiltration dependent upon the magnitude and timing of rainfall events.

Numerical modelling has been used to quantify the infiltration of rainfall and irrigation water from the root zone of the crop to groundwater. This modelling, described in Appendix H, utilised an unsaturated flow infiltration model—the LEACHM model (Hutson and Wagenet

1992). LEACHM is a water balance model that is able to evaluate water movement through unsaturated soils as well as water uptake by crops.

The results of the LEACHM modelling show that the rate of accession to groundwater from cropping areas would be in the range 54-119 mm/a and that for average meteorological and soil conditions the rate is expected to be 94 mm/a. For groundwater management planning purposes an average rate of 100 mm/a has been adopted for the Project. It is noted that variations in soil conditions would result in local variations in the groundwater accession rate. However, regional changes in groundwater levels would be representative of accession rates over large areas, justifying the use of an average rate for the current planning purposes. Further justification for the approach and accession rates adopted for the Project has been provided by recent studies by Sinclair Knight Merz (1998) that derived an average rate of accession to groundwater from cropped areas in ORIA Stage 1 of approximately 100 mm/a in 1996.

6.5 GROUNDWATER MANAGEMENT STRATEGY

6.5.1 Groundwater modelling

The potential impacts on the groundwater environment were assessed using a numerical groundwater model developed using the USGS MODFLOW software package and the hydrogeological database held by the Water and Rivers Commission and the Department of Lands, Planning and Environment. The model, described in Appendix I, predicts groundwater levels with time on the basis of information supplied regarding geology, infiltration from the surface and groundwater abstractions by bores.

The most critical parameter of the groundwater model—the rate of aquifer recharge or accession rate—was assumed to be 2 mm/d (the maximum value adopted for design) from the irrigation infrastructure (see Section 6.4.1) and 100 mm/a from the cropped areas (see Section 6.4.2).

The USGS MODFLOW model was used as a design tool as well as for predicting groundwater response for the proposed groundwater management strategy. The range of model runs performed is outlined in Appendix I. Many of the model runs, including the proposed groundwater management strategy, involved the use of bores to partially dewater aquifers underlying the Project Area. In these cases the modelling was undertaken assuming a generally uniform distribution of the dewatering bores in areas where aquifers were known to have sufficient permeability to allow long term pumping.

Further exploration drilling would be completed and trial production bores installed and tested prior to the commencement of full-scale irrigation. The necessary optimisation studies for the dewatering bore system would then be undertaken.

All of the modelling scenarios assumed a period of fifty years to represent long-term operation of the Project. This period reflects a sensible limit on the use of the available data and the accuracy of the modelling based upon these data. Sustainability of irrigated agriculture in the Project Area for periods longer than 50 years was assumed to be demonstrated if the rate of groundwater rise at 50 years was small and within the accuracy normally expected of groundwater modelling. This situation was achieved for an accession rate of 100 mm/a from the cropped areas by running the model with progressively more dewatering bores and then optimising the time of commencement of pumping and the pumping rate. The proposed groundwater recovery system in described further in Section 6.5.2.

It is noted that none of the modelling scenarios included the effects of field drains that may be used as a groundwater management measure in the future. This was a deliberate action as the model was used to identify the extent of the cropped area that is likely to require this form of groundwater management. The result of omitting the field drains from the modelling scenarios is that the predicted groundwater levels for the proposed management strategy (see Section 6.5.3) continue to rise, albeit slowly, in some areas after fifty years.

Field drains consist of a series of perforated pipes laid below the surface that would allow the entry and collection of groundwater, however, they are only effective when groundwater levels are at or above the level at which the drains are laid.

6.5.2 Groundwater recovery and disposal

The proposed groundwater management strategy would require the direct control of groundwater levels by the long-term use of dewatering bores and, to a lesser extent, field drains.

Dewatering bores at depths of 10–30 m would extract groundwater from the permeable palaeochannels that underlie much of the Project Area. The optimal locations for the dewatering bores (ultimately numbering about thirty) would be determined following further field investigations. Current planning assumes that the dewatering bores would be uniformly spread over areas underlain by palaeochannels or other permeable strata, with minor variations in location made to accommodate infrastructure and farm unit boundaries. A conceptual layout of dewatering bore locations and buried collector pipelines are shown in Figure 6.1.

The results of the groundwater modelling undertaken for this Project indicate that dewatering bores and field drains may only need to be operated after approximately ten years of cropping; even after that time their installation could be phased in over a number of years. Groundwater collected by the dewatering bores and field drains would therefore be variable in time both in terms of quantity and quality, with the latter initially being highly dependent upon existing groundwater quality.

Collected groundwater would initially be disposed of as irrigation water, following dilution in the irrigation channels with water sourced from Lake Kununurra. In some areas the quality and quantity of the extracted groundwater would be such as would allow this practice to be the long-term method of disposal. However, project planning is currently based upon the conservative assumption that, in the long term, all extracted groundwater may be too saline for re-use as irrigation water and would therefore require disposal to the tidal sections of the Keep River and Sandy Creek downstream of the Project Area. These receiving waters would be marine (about 35,000 mg/L TDS). The quantities and likely range of water quality for the extracted groundwater, based upon this assumption, are given in Table 6.1.

Table 6.1 Estimated long-term dewatering rates

Location	Approximate quantity (ML/a)	Likely level of salinity (mg/L)	Likely discharge location
Weaber Plain	8,600	2,200–2,600	Tidal section of Keep River
Knox Creek Plain	1,800	2,200–13,000	Tidal section of Keep River
Keep River Plain	1,100	2,200–20,000	Tidal section of Keep River and Sandy Creek

The collector pipelines would be fabricated from corrosion resistant polyethelyne or PVC. They would also be buried in order to minimise the risk of damage, and wherever possible, follow roads or tracks in order to facilitate access for maintenance.

The potential impacts arising from the discharge of collected groundwater is discussed in Section 10.4.5

6.5.3 Predicted changes to groundwater levels

The USGS MODFLOW groundwater modelling (Appendix I) indicates that groundwater levels would rise under all areas used for irrigated agriculture but that groundwater pumping would successfully limit the groundwater mounding beneath most of the Project Area. The effectiveness of groundwater pumping for water-level control in the ORIA Stage 1 area has also been investigated and confirmed by the Water and Rivers Commission and described by O'Boy (1997, 1998). Groundwater pumping is also used extensively as a means of groundwater control in the Burdekin River Irrigation Area in Queensland.

In the long term, groundwater pumping would be the primary management tool for controlling rising water levels. Some isolated areas would require the use of field drains to control groundwater levels in the long term.

It is noted that the predicted groundwater levels are based upon average hydrological parameters, and average accession rates (Section 6.4.2 refers). This approach is valid for planning purposes due to the regional response of groundwater systems. However, in reality, the assumed parameters would exhibit a degree of spatial variation, and local variations in the predicted responses would be expected. In extreme cases these variations between observed and predicted response may be significant.

The modelling was used to classify the Project Area into Groundwater Management Zones. Zones where groundwater levels rise to within 5 m of ground surface in the absence of any dewatering system during the fifty-year simulation period are deemed to require groundwater control. Zones where groundwater levels rise to within 1 m of ground surface in the absence of any dewatering system are deemed to be susceptible to waterlogging. The classification system used to define Groundwater Management Zones for the Project is provided in Table 6.2. Zone 1 denotes an area within which no management is required, whilst Zone 5 denotes an area generally unsuitable for long-term irrigation.

The Groundwater Management Zone map developed from the results of the groundwater modelling is presented as Figure 6.2. It is noted that the Project Area includes no lands categorised within either Zone 1 or Zone 5. A more detailed description of predicted changes to groundwater levels beneath the Weaber Plain, the Keep River Plain and the Knox Creek Plain follows. Section 6.5.4 describes the predicted changes to groundwater quality.

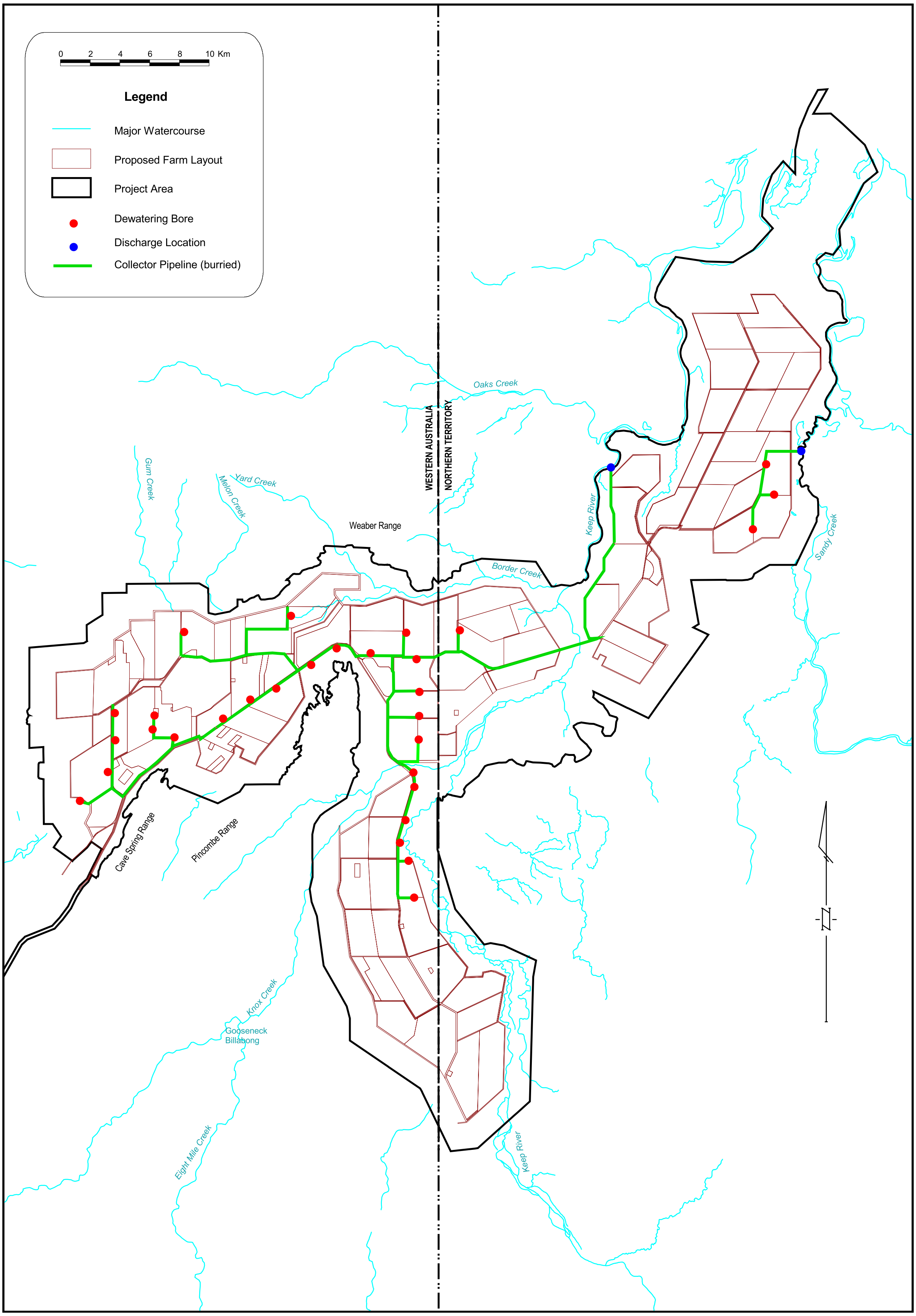

Figure 6.1 Conceptual dewatering bore layout

Table 6.2 Groundwater management classification system

Classification	Description	Management action required
Zone 1—Passive groundwater management	Groundwater readily drains naturally and a relatively deep steady-state water-level (equilibrium condition) would be readily achieved. Groundwater control measures would not be required.	None.
Zone 2—Minor groundwater management	Natural groundwater drainage is not sufficient to prevent rising water-levels but, combined with available groundwater storage, is sufficient to accept the accessions. These areas would remain viable for irrigation for fifty years, without groundwater control.	Monitoring of groundwater level and quality.
Zone 3—Moderate groundwater management	Natural groundwater drainage is not sufficient to prevent rising water-levels. Some areas may have significant groundwater storage capacity or the area may be underlain by permeable units that allow groundwater pumping from bores. These areas would require groundwater control to remain viable for long-term irrigation.	Monitoring of groundwater level and quality; dewatering bores.
Zone 4—Intensive groundwater management	Natural groundwater drainage is poor and water-levels rise significantly under irrigation, leading to possible waterlogging. Groundwater control via dewatering bores would be required for viable long-term irrigation. Field drains may be required in some areas.	Monitoring of groundwater level and quality; dewatering bores; field drains.
Zone 5—Unsuitable for long-term irrigation	Natural groundwater drainage is very poor and initial groundwater levels are high; rapid waterlogging and/or salinisation expected. Groundwater control would not be practical using either bores or field drains. Long-term irrigation would not be viable.	Long-term irrigation avoided.

Weaber Plain

The Weaber Plain falls into Zones 3 and 4, both of which require groundwater control to ensure water-levels are maintained at suitably deep levels.

Predicted accessions from the M2 Channel, and in particular the balancing storage dams, would add significantly to the rate of water-level rise in adjacent areas. Some natural groundwater drainage would occur as throughflow within the palaeochannel, however, the bulk of the accession water would enter groundwater storage (i.e. rising water-table) or be discharged via pumping from bores.

For most of the Weaber Plain, the initial groundwater levels are 10 m and commonly more than 15 m beneath ground level. The length of time taken for the water-table to rise to near ground level would therefore allow for regular review of the response of the groundwater regime to irrigation and for intervention to be timed to suit the observed responses.

The north-western portion of the Weaber Plain area is underlain by rock with low permeability and has an initial shallow water-table (less than 10 m below ground level). The absence of a permeable subsurface unit (on current knowledge) implies that pumping is unlikely to be effective in this area. Agricultural field drains would be required in this area if groundwater mounding approached the surface. A large portion of this area has significant conservation value and would be devoted to conservation, thereby mitigating potential increases in accessions to groundwater and consequential impacts associated with rising groundwater levels in this area (Chapter 10 refers).

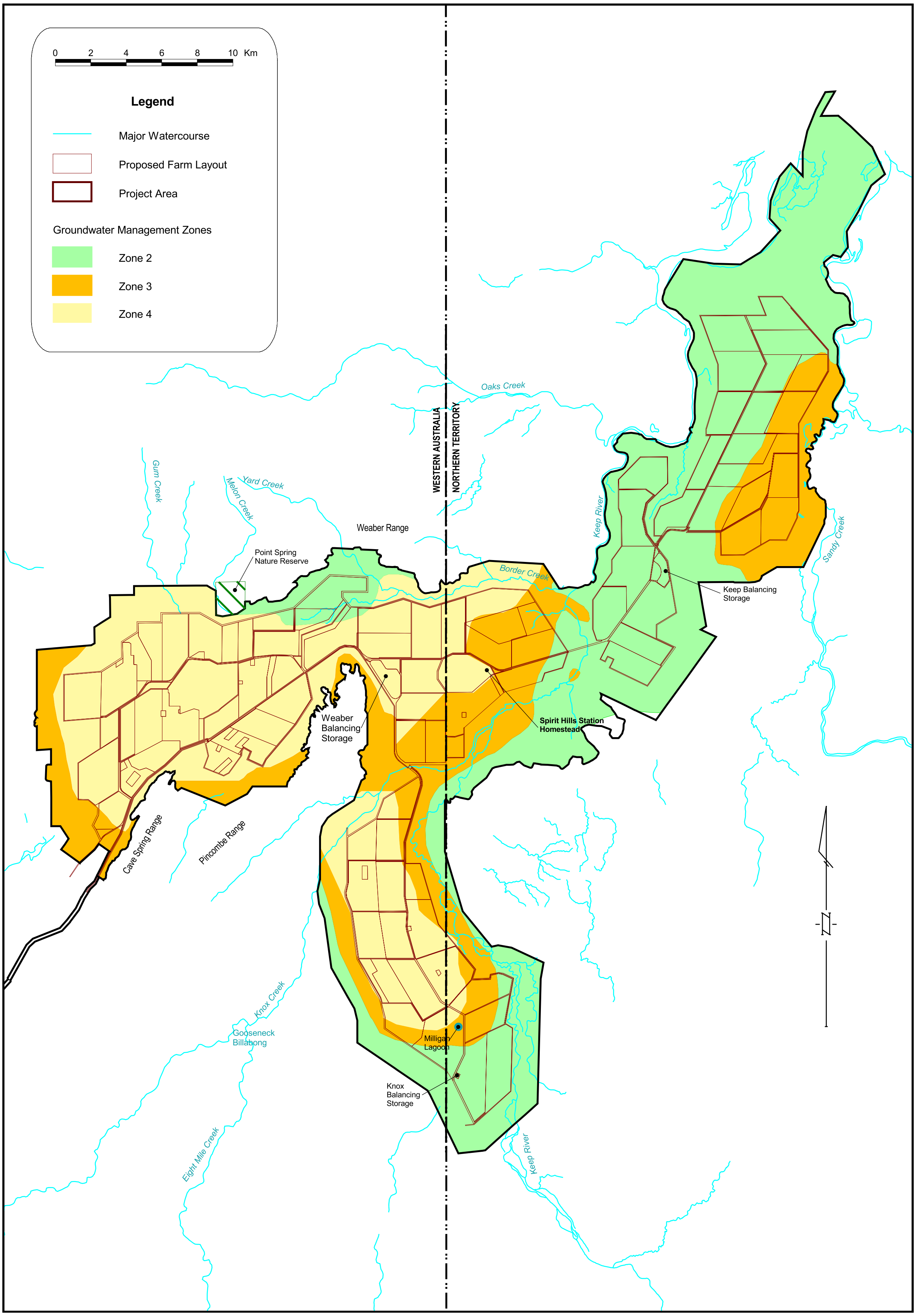

Figure 6.2 Groundwater management zones

As mentioned in Section 6.3.1, the wetland associated with Point Spring is associated with a different system to the alluvial sediments of the Weaber Plain, hence impacts to the wetland are not predicted.

A groundwater mound is predicted to develop to the north of the Weaber balancing storage dam, where the palaeochannel diverts around a Cockatoo Land System inlier within the black-soil plains. It is envisaged that closely spaced dewatering bores and possibly field drains would be sufficient to control the lateral spread of this groundwater mound into adjacent areas.

Keep River Plain

The Keep River Plain has been classified as Groundwater Management Zones 2 and 3.

The lower Keep River Plain is naturally well drained via groundwater throughflow and lateral discharge into the Keep River and Sandy Creek, and the modelling results indicate that it quickly approaches equilibrium conditions when dewatered using bores. The initial water-levels are within 10 m of the surface and in the lower-lying flanking areas within 5 m. Because of the shallow water-table, there may not be a significant response time to observe and plan for water-level rises and therefore production dewatering bores would be installed early in the Project to be available as needed.

The modelling results indicate that the upper Keep River Plain would continue to experience water-level rise throughout the fifty-year simulation period, albeit at rates that would be relatively small. The initial depth to groundwater in the upper Keep River Plain is greater than 10 m and this factor, together with natural drainage and dewatering, should prevent unacceptably shallow water-tables developing over the life of the Project.

Knox Creek Plain

The Knox Creek Plain has been categorised in Groundwater Management Zones 2, 3 and 4. All areas of the Knox Creek Plain proposed for development have initial groundwater levels at depths greater than 10 m and largely at depths below 15 m.

The development area would exclude Milligan Lagoon, a surface expression of a locally perched water-table. Drilling undertaken for the Project has shown that the regional groundwater level is approximately 20 m below the water-level in Milligan Lagoon, confirming the presence of two independent aquifers in this locality. Milligan Lagoon occurs within this shallow perched aquifer, which is hydrologically isolated from the regional aquifer that would be impacted by irrigation.

Current planning for the Project recognises the potential interaction of Milligan Lagoon with the surface hydrology of the surrounding area. The location and extent of hillside drain HD×1 would be reviewed further during detailed design work in order to minimise any impact on this water body.

As with the Weaber Plain and the upper Keep River Plain, the groundwater modelling results indicate that groundwater levels on the Knox Creek plain would rise for the entire fifty-year simulation. However, the significant depth to the existing water-table would provide long lead times before water-levels rise to within 5 m of the surface—approximately twenty years with no dewatering.

The groundwater modelling assumed that dewatering using bores would not be effective in the shallow basement rocks (mostly limestone) that underlie the Western Knox Creek Plain. Based on this assumption, the model results indicate that the western areas of the Knox Creek Plain may experience water-tables within 5 m of the surface after about thirty years and local waterlogging after forty years, even with pumping from the palaeochannel aquifer immediately to the east. It may therefore be necessary to control the groundwater mound beneath the western Knox Creek Plain using field drains. However, further investigations would be undertaken prior to development to ascertain whether this area contains zones of high permeability, as would normally be associated with limestone basement complexes.

Impacts on watercourses

The USGS MODLOW groundwater model was also utilised to predict groundwater discharges to watercourses due to regional rises in groundwater levels. However, the model was not utilised to differentiate between discharges that would be taken up by evapotranspiration by riparian and other vegetation, direct evaporation from soil, and groundwater induced streamflow. The latter would only occur if the discharge rate exceeded the combined evapotranspiration and direct evaporation rates and the water-table reached the watercourse bed level. The predicted maximum rates of groundwater discharges to the non-tidal portions of the regional rivers and creeks are summarised in Table 6.3.

Table 6.3 Predicted maximum groundwater-induced discharges to non-tidal portions of watercourses

Year	Keep River		Knox Creek		Sandy Creek	
	ML/a	mm/a*	ML/a	mm/a*	ML/a	mm/a*
10	7,048	500	0	0	1,118	220
20	8,117	580	0	0	1,134	230
30	8,847	630	25	5	1,168	230
40	9,361	660	61	10	1,205	240
50	9,767	700	96	20	1,236	250

* *Discharge rate over affected portion of watercourse, assuming 500 m width.*

Table 6.3 also provides an estimate of the discharge rate by area along the potentially affected sections of these watercourses. The 500 m width assumed in these calculations equates to the minimum width of riparian vegetation mapped along these watercourses (Section 7.2.1 refers). It should be noted that the width of riparian vegetation that would remain following development would exceed 1000 m at most locations. Furthermore, the predicted rate of groundwater discharge is lower than the net evaporation rate of 2,100 mm/a for the region (Section 4.1 refers), which implies a low risk of permanent streamflows in the existing ephemeral portions of the watercourses as a result of the proposed development.

The use of the groundwater by vegetation, and direct evaporation from the soil, would result in the concentration of salts. From the information currently available it is not possible to determine with accuracy whether this effect would be detrimental to riparian and other vegetation or whether the salts would be flushed from the soil profile during annual flooding of the watercourses in the wet season. For this reason, health of riparian vegetation and groundwater levels and quality would routinely be monitored as part of the project operations by the EME (Chapter 16 refers). The groundwater pumping strategy would include provision for capture of additional groundwater adjacent to the watercourses if considered necessary.

6.5.4 Predicted changes to groundwater quality

Salinity

The quality of the irrigation water sourced from Lake Kununurra (salinity level of about 160 mg/L TDS) is a major factor in determining the quality of any groundwater accessions. Another factor of importance is the relative contribution of accessions from the cropping areas, which may have elevated salinity levels due to the effects of evapotranspiration, and seepage of irrigation water from infrastructure.

Mass balance calculations based upon the relative accession rates described in this ERMP/draft EIS indicate that the average salinity of all the accessions combined would be about 2,200 mg/L TDS. This calculation assumes that the salts in the irrigation water would behave in a conservative manner, with no chemical reactions or precipitation from solution occurring. In reality, the combined effect of evapotranspiration increasing the concentration of salts and the high soil alkalinity (greater than pH 9 for most of the black soils within the Project Area) would cause the precipitation of carbonates and bicarbonates from the accession water. These salts contribute over half (120 mg/L alkalinity as bicarbonate) of the total salinity of the irrigation water, and hence the assumption that the dissolved salts would behave in a conservative manner could significantly overestimate the salinity of the accession water from the Project Area (although the magnitude of the overestimation cannot be quantified with the available data).

The groundwater of the Weaber Plain is fresh to brackish. In the west the salinity is around 1,000 mg/L TDS (Nixon 1997e). Throughout the southern and central parts of the plain, groundwater salinity ranges from 70 mg/L TDS to 2,600 mg/L TDS. The calculated salinity of the groundwater accessions of about 2,200 mg/L TDS is comparable to, but slightly higher than, the general groundwater salinity beneath the Weaber Plain and therefore no cumulative impacts are expected.

The groundwater salinity beneath the Keep River Plain is more variable than for the other areas, ranging from about 100 mg/L TDS to 51,000 mg/L TDS. It is likely that the higher salinity is influenced mostly by the proximity of the tidal portions of the Keep River and Sandy Creek, which are hydrologically connected to the groundwater regime. The salinity of the accession water would be lower than the salinity of the existing groundwater beneath much of the lower Keep River Plain. Negligible impacts are therefore predicted. In the lower Keep River Plain, it is possible that soil salts may provide a significant contribution, to the net salinity of the accession water, and effectively raise the salinity of the accession water to near that of the existing groundwater.

The groundwater salinity in the Knox Creek Plain ranges from 60 mg/L TDS to 13,000 mg/L TDS, but in general is around 1,000 mg/L TDS (Nixon 1997a). The higher salinity is generally associated with the shale basement complex where downward flushing is inhibited. The accession water salinity would be within the observed range of groundwater salinity and therefore no significant impacts are expected.

Nutrients and chemicals

The black soils typical of the Project Area are known to be highly effective in binding phosphorus, and elevated levels of this nutrient are not anticipated in the groundwaters beneath the Project Area.

Migration of nitrogen to groundwater is generally less affected by soil conditions than phosphorous. The Water and Rivers Commission (O'Boy 1998) measured nitrogen levels (as total nitrate) in groundwaters below the Ivanhoe Plain and the Packsaddle Plain in ORIA Stage 1. The results show total nitrate level (calculated as nitrogen) of approximately 2 mg/L and 1.2 mg/L in groundwater beneath the Ivanhoe Plain and the Packsaddle Plain respectively. These levels are similar to naturally occurring levels in groundwater beneath the Project Area, which are generally below 1–2 mg/L (Section 6.3.2).

It is postulated that the current nitrogen levels in groundwater under ORIA Stage 1 would not be representative of future levels under the Project Area due to the higher rates of accessions to groundwater in ORIA Stage 1 providing additional dilution. For example, the predicted average salinity of groundwater accessions for the Project is about 2,200 mg/L TDS, whereas measured salinity levels in ORIA Stage 1 are 1,200–1,800 mg/L TDS for the Ivanhoe Plain and 430–600 mg/L TDS for the Packsaddle Plain (O'Boy 1998). If the additional dilution in ORIA Stage 1 is taken into account, it would be reasonable to expect that total nitrate levels in groundwater in the Project Area would be in the range of 3.1–5.2 mg/L. Although the predicted levels are about twice the naturally occurring levels, they remain relatively low. For example, the drinking-water guideline value is 10 mg/L (ANZECC 1992).

The observation that black soils are effective in preventing the migration of pesticides from the surface to groundwater, made in other irrigation areas in Australia, has been confirmed by analyses undertaken by the Water and Rivers Commission of groundwater beneath ORIA Stage 1. The analyses involved testing water samples from two bores undergoing long-term pumping tests: one on the Ivanhoe Plain and the other on the Packsaddle Plain. The analyses included a comprehensive range of organochlorine and organophosphate pesticides currently or previously used in the ORIA, at a detection limit of 0.01 µg/L per chemical. The results (O'Boy 1998) showed that no pesticides (organochlorines or organophosphates) were detected in the water samples.

6.5.5 Monitoring programme

Groundwater monitoring for the Project would commence with delineation drilling across the interpreted position of the palaeochannel aquifers in order to define their actual position beneath the irrigation area.

An extensive network of groundwater monitoring bores would also be installed within and adjacent to the irrigation area prior to the commencement of irrigation. This network would include bore transects aligned perpendicular to the Keep River and Sandy Creek to acquire additional data for the better understanding of the river–groundwater interactions, and the establishment of monitoring bores adjacent to Milligan Lagoon.

Groundwater samples would be collected during the delineation drilling to quantify the vertical and horizontal water quality distribution.

Test dewatering bores would be installed and tested to confirm aquifer yields and the response of the aquifers to pumping. The data collected by the above programmes would be used to continually update the groundwater model and to optimise the extent and timing of installation of the groundwater management system.

The quality of groundwater adjacent to watercourses would be monitored. The groundwater pumping strategy would include provision for the capture of additional groundwater adjacent to the watercourses if considered necessary.