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Preliminary soil and groundwater assessment of the Mantinea Development area, East Kimberley, Western Australia

Resource management technical report 389

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Cover: View across the Mantinea Development area to House Roof Hill (photo: RJ George)

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The authors acknowledge prior work by Richard Nixon (Global Groundwater, previously Geological Survey of Western Australia) who supervised and documented the drilling program on the Mantinea Development area. Richard also peer reviewed this report.

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Summary

In 2008, the Ord Stage 2 or 'Ord East Kimberley Expansion Project' was initiated by the Western Australian Government. The goal of the project was to advance development in the East Kimberley and to bring to market the Weaber Plain (Goomig Farmlands) and Knox Plain. In addition to the existing Ord River Irrigation Area (ORIA) Stage 1 (14 000ha), current Goomig and proposed Knox Plain areas (14 300ha), an estimated 50 000ha of land has potential for irrigation in the region.

One of the areas proposed for future development is the Mantinea Development area. It is located on the south bank of the Ord River, 30km from Kununurra (Figure 1.1). It is north-west of the existing ORIA, which is located on the Ivanhoe and Packsaddle plains, and south-west of the most recent Stage 2 Goomig Farmlands, released in 2012.

For the Mantinea Development, the state government is seeking a proponent from the private sector to manage the development process and operate the new farmlands created. The potential development area covers about 9500ha, 430ha of which has been set aside in the Mantinea conservation excision.

To support the development process, DAFWA has reviewed relevant soil and water data and undertaken a preliminary assessment of that information.

The Mantinea Flat – Carlton Plain area was identified as potentially suitable for irrigated agriculture by the Department of Agriculture and CSIRO as early as 1944, following soil surveys of about 12 000ha in the area.

Preliminary soil survey results show that the soils of the proposed development area comprise a mixture of modern alluvial sediments, from fine cracking clays (1500ha, 17%) to sands and loams (6600ha, 73%), and stony soils (800ha, 10%). From this limited data, 4796ha (53%) of the proposed development area has a potentially high capability for irrigated agriculture, 2876ha (32%) is potentially capable but requires further investigation, and 1395ha (15%) of the area has a low capability. Areas assessed as having low capability for irrigated agriculture predominantly have salinity risk, poor drainage, shallow basement or unsuitable soil types.

This preliminary capability assessment is based on limited, historical data and conditions. A recent airborne electromagnetics (AEM) survey of the area indicates that subsoil conductivities are highly variable across the Mantinea Development area, including portions of the area with high capability for irrigated agriculture. If groundwater was to rise as a result of irrigation, it would constitute a change in conditions that may reduce the land capability, especially for areas with high subsoil salinities, which may include the well-drained sandy soils, which are currently assessed as having high capability.

Investigations of groundwater conditions within the Mantinea Development area started in 1996 by the Geological Survey of Western Australia. Groundwater level and salinity data has been, and still is, collected by the Department of Water. Analyses of the salt stores within the regolith were also undertaken using AEM data collected by Geoscience Australia (Lawrie et al. 2010), and salinity hazard maps created.

Analysis of the available bore data shows groundwater levels are within 4–7m of the surface and are marginally (1200mg/L total dissolved solids (TDS)) to highly saline

(28 900mg/L). Groundwater at stock bores, assumed to be screened across the sediments and fractured basement, is fresh (<1000mg/L). Regolith conductivity data indicates that salt stores are high to very high in western areas (associated with marine sediments and tidal influence, which extend as far as the Bend of the Ord River) and appear to peak at a depth at or near the current watertable. Low to moderate salt stores occur in the eastern areas, adjacent to the Ord River and in areas of shallow basement.

Groundwater trend analysis indicates that groundwater levels have remained relatively stable over the period 1996–2013, apart from one bore drilled into the Proterozoic basement (on the southern boundary of the proposed development area), which has a rising trend (0.3 metres per year (m/y). This observation is in contrast to hydrograph analysis for the Goomig and Knox, where groundwater levels have risen at least 5m because of increased rainfall since 1993.

The lack of long-term groundwater rise in the Mantinea Development area and the recession of groundwater levels after prolonged wet seasons indicate permeability within the shallow alluvial and marine sediments and hydraulic connection to the Ord River. The salinity patterns indicated by AEM data support the possibility of connection to the Ord River. However, once cleared and irrigated, there is a risk that the aquifer discharge potential would not be sufficient to prevent groundwater rise to within the critical depth for irrigated crops. Under these circumstances, and considering the soil analysis, locally high background salt stores, tidal influence and aquifer salinity levels, groundwater management would likely be required to manage the risk of soil salinity in parts of the development area. The need for management would be greatest in the west, where higher salt stores and shallower watertables occur.

Recommendations for further investigations to quantify and mitigate waterlogging and salinity risks are provided in Section 6.

1 Introduction

In 2008, the Ord Stage 2 or ‘Ord East Kimberley Expansion Project’ was initiated by the Western Australian Government. The project started with the goal of developing irrigated agriculture on the Weaber Plain, later termed the ‘Goomig’ irrigation area, and on the Knox Plain.

As part of the Expansion Project (based on many decades of planning), several other parcels of land were recognised as likely to be suitable for irrigated agriculture, namely the Keep River Plain (nominally 14 000ha) in the Northern Territory, West Bank (about 1000ha) and Mantinea Development area (estimated agricultural suitability of up to 5000ha). Together with smaller areas on the East Bank (1200ha) and freehold land on Carlton Plain (8000ha), the combined area of potential land that remains to be developed is more than 32 000ha. This land does not include Stage 3 areas of cockatoo sands along Victoria Highway (2200ha), Carlton Hill Station (5600ha) and the Bonaparte Plain (about 30 000ha).

The Mantinea Development area (9500ha, including 430ha which has been set aside in the Mantinea conservation excision), which is the subject of this review, is located on the south bank of the Ord River, 30km north-west of Kununurra, in the far north-east of Western Australia (Figure 1.1). It is north-west of the existing, 14 000ha ORIA on the Ivanhoe and Packsaddle Plains, and south-west of the Ord Stage 2 developments on the Weaber Plain (Goomig Farmlands).

Mantinea was identified as potentially suitable for irrigated agriculture by the Department of Agriculture and CSIRO as early as 1944, following a soil survey of about 12 000ha in the area north and south of the Ord River (Burvill 1991). The survey showed the soils comprised a mixture of alluvial sediments, from fine-textured cracking clays to coarser loams and sands deposited by the Ord River.

Investigations into the area’s hydrology and groundwater conditions did not begin until 1993 (Laws 1993). A program of drilling investigations was then conducted by the Geological Survey of Western Australia (GSWA) in 1996–97 (Nixon 1996, 1997) and later, in 2008, acquisition and interpretation of airborne electromagnetic (AEM) and related topographic and geophysical data was completed by Geoscience Australia (Lawrie et al. 2010).

This review reports the current understanding of the status of soils and water-related conditions on the Mantinea Development area to underpin continued interest in land for agriculture in the region.

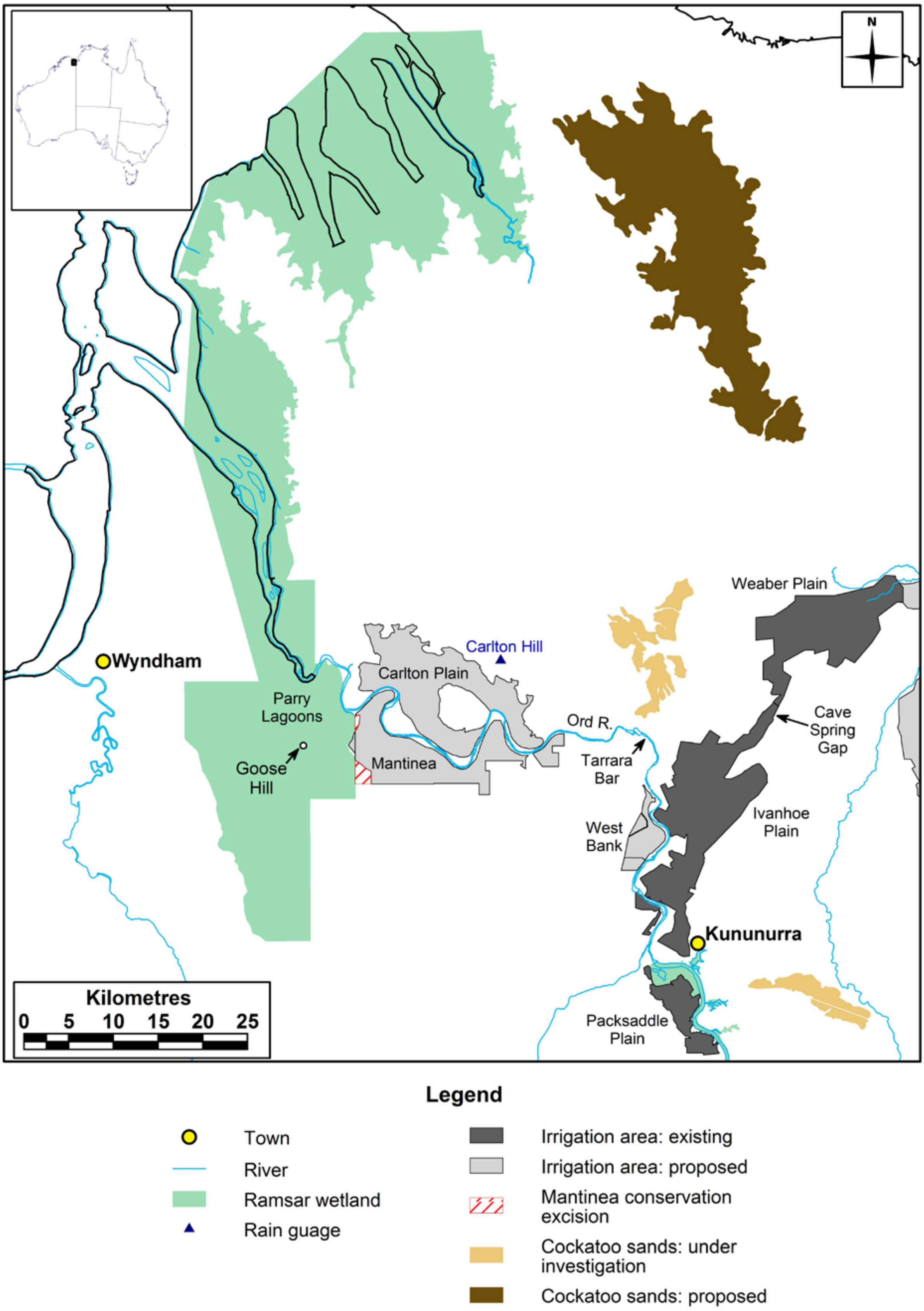


Figure 1.1 Mantinea Development area locality map

1.1 Physiography

The Mantinea Flat is a gently inclined plain comprising an undulating and irregular topography caused by multiple phases of deposition and erosion by the Ord River. It extends 23km from Mantinea Creek to Goose Hill (Figure 1.1, Figure 1.2). Lower-lying areas west of the development area sit at about 4mAHD. The highest points of the flat adjacent to the Ord River in the east of the area rise to over 20mAHD.

The land surface around the base of Goose Hill, to the west of the proposed development area, is only 3m above high tide level and very high tides inundate the old river meander sediments (O'Boy et al. 2001). The Ramsar-listed, tidally inundated Parry Lagoons lie to the west. The broad, steep-sided rectangular trench of the Ord River separates the Mantinea Development area from the Carlton Plain. Tidal influences extend up the Ord River as far as the Bend of the Ord River, which lies immediately south of House Roof Hill (O'Boy et al. 2001) (Figure 1.2).

The southern extent of Mantinea Flat is defined by ranges of rocky sandstone hills, which rise to over 40mAHD, outside the development area. Drainage lines emanating from these hills predominantly flow north and west towards Salt Water Creek and Goose Hill Creek. Salt Water Creek discharges to the Ord River just west of the development area; Goose Hill Creek discharges via old river meanders to the Ord Estuary.

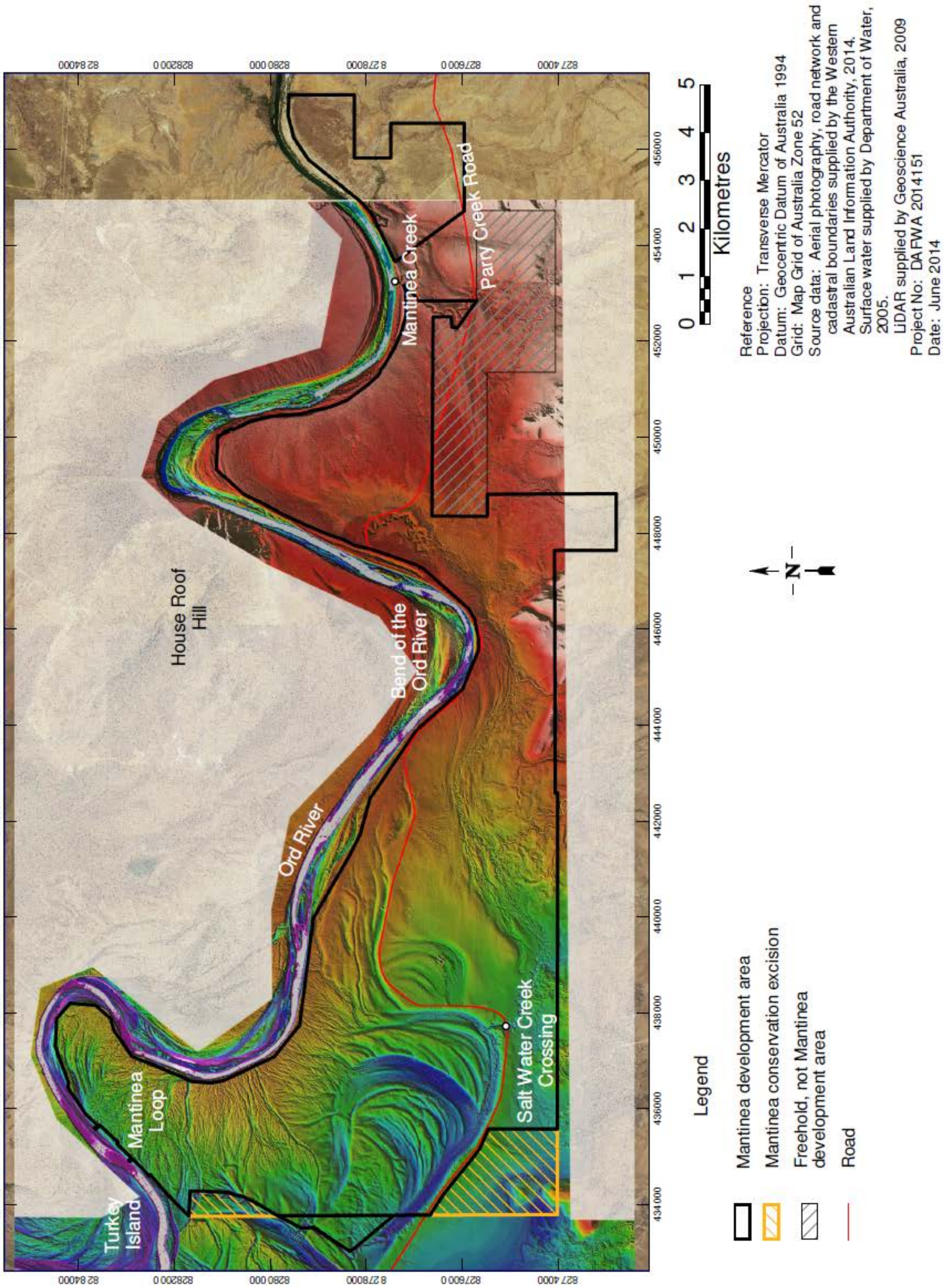


Figure 1.2 Physiographic features of the Mantinea Development area based on the LiDAR digital elevation model (source: Lawrie et al. 2010). Elevation ranges from 3mAHD (violet) to more than 30mAHD (white)

1.2 Climate

The climate is semi-arid, dry tropics. Two distinct seasons occur: the ‘wet’ monsoonal period from November to April when 90% of the annual rainfall occurs, and the ‘dry’ from May to October. Annual pan evaporation is 2800–3000mm.

Throughout the Kimberley, a distinct increase in annual rainfall occurred after 1993 and is shown by a plot of annual and 10-year moving average rainfall at Carlton Hill (Figure 1.3), which is located to the north of the Ord River, 7km from Mantinea Development area.

Figure 1.3 also shows that even though the early 1900s and the 1940s contained wetter phases, they do not contain consecutive runs of extremely wet years as seen since 1993. The average annual rainfall for the period 1897–1992 was 770mm, and for the period since 1993, the average was 1035mm, a 34% increase. The wettest year on record at Carlton Hill was 2000, when 1507mm of rainfall fell. Furthermore, the period 1993–2013 contains five of the 10 wettest years on record, all of which are above the 93rd percentile.

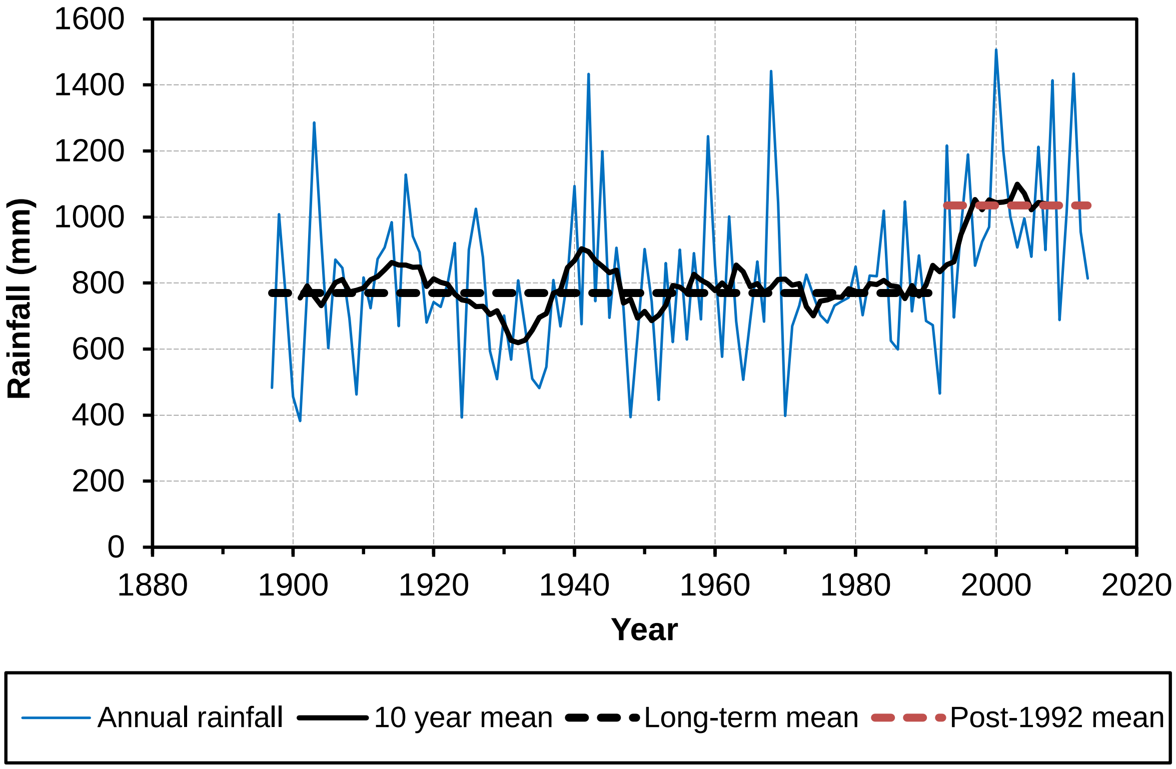


Figure 1.3 Rainfall data for Carlton Hill, located 7km north of the Mantinea Development area

2 Soils

2.1 Soil mapping

The soils of the Mantinea Flat – Goose Hill area were first surveyed in detail in 1944 by a soil survey team led by George Burvill, Department of Agriculture, WA (Burvill 1944, 1991). This survey covered an area of about 12 100ha.

The initial assessment of flood irrigation potential of the Mantinea area was less favourable than for the Carlton Reach Plain (now called the Ivanhoe Plain, which is currently under irrigation). When comparing the two areas, Burvill (1991) noted that for Mantinea, “the drainage and hydrology are quite different: seasonal flooding is sometimes extensive, the soil pattern is more complex, and the subsoil of the clay plains becomes progressively more saline approaching Goose Hill. Also the alluvial deposits east and north of Goose Hill in old river meanders have an irregular surface which may be unsuitable for an irrigation layout.”

Some of these issues are less important today, especially the risk of wet season inundation, which has been reduced as a result of flood reduction achieved with the construction of Lake Argyle. The original surveys were aimed at flat land with clay soils that could be flood irrigated. Irrigation design and methods are now more sophisticated and capable of catering for permeable soils on sloping land.

The issues of complex soil patterns, irregular landforms, poor drainage and the salinity of subsoils in the clay plains are still important restrictions to all forms of irrigation and need to be considered.

The soil mapping of the 1944 survey was poorly aligned with topographic features in some areas — not surprising given the lack of benchmarks and low resolution aerial photography available at the time — and in the 1990s the original map units were realigned using high-resolution aerial photography, cadastral maps and limited fieldwork. During the 1944 survey, a meander loop in the Ord River north-west of the original survey area was omitted. These sandy alluvial soils are now considered to be highly suitable for some forms of irrigation and a reconnaissance survey was conducted in 1994 to extend soil survey coverage of potentially suitable lands (Schoknecht & Grose 1996).

The entire East Kimberley is covered by regional-scale land system mapping which was conducted by CSIRO in 1949 and 1952 and published in 1970 (Stewart et al. 1970). This land system mapping was updated and reported in a consistent way for the entire Kimberley Region by Payne and Schoknecht (2011).

Between 2002 and 2005, many areas of the Ord Catchment, including the Mantinea Development area, were covered by land unit mapping (Schoknecht et al. 2005, Handasyde et al. 2009). Land units are the unmapped components of land system mapping and hence show more detail in regional-scale mapping (see Schoknecht et al. (2004) for the soil-landscape mapping hierarchy). This land unit mapping has not been published but has been included in this Mantinea review where detailed soil information is not available. The Parry Lagoons area was mapped for the lower Ord Ramsar site draft management report (Hale 2008). The mapping was spatially corrected and incorporated into the land unit mapping (Schoknecht et al. 2005).

Most of the soil profile site data, which was collected by Burvill in 1944, has not been captured in DAFWA's soil profile database. A limited analysis of these data is presented in Burvill (1991) but coordinates of these sites are not available. In 1994, the Ord Development Council collected several soil samples to a depth of 150cm and commissioned several chemical analyses on the samples.

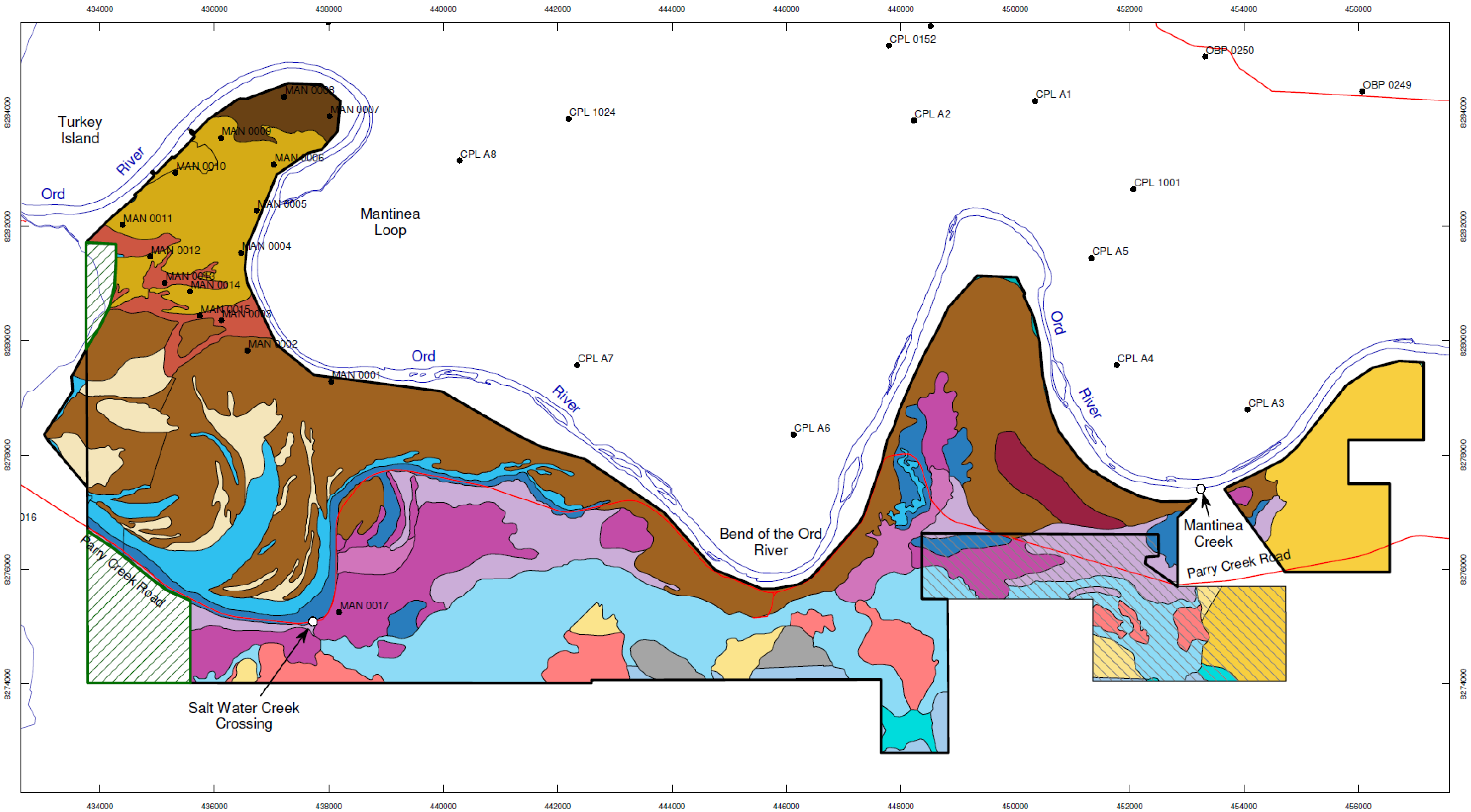
Schoknecht and Grose (1996) performed a reconnaissance soil survey of the Mantinea Loop and collected samples at 17 sites. These were analysed in the field for pH and electrical conductivity (EC). Descriptions of site and soil profile morphology are archived in DAFWA's soil profile database. At the same time, a drilling program was completed as part of a hydrogeological investigation by the GSWA (Nixon 1996). Schoknecht and Grose (1996) sampled the drill spoil from four of the bores from that program.

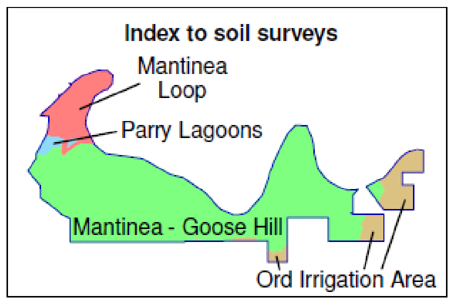
A composite map of all available soil and land unit mapping, using the best available mapping where datasets overlap, is presented in Figure 2.1. Table A1 summarises the map units (grouped by survey), with comments regarding capability for irrigated agriculture.

Legend

Label	Map unit description
A	**Group A soils: old levee and meander phase.** Variable deep light textured brown soils (e.g. loamy sands to sandy loams grading very gradually to clay loam). Near Ord River in old meanders and old levees.
A1	**Group A soils: flat plain phase.** Flat to gently undulating plain with numerous small depressions and ridges. Brown fine sandy loam alluvial soils.
A2	**Group A soils: relict flood channel phase.** Undulating plain with numerous distinct ridges, channels and depressions (relict Ord flood channels). Brown fine sandy loam alluvial soils.
A3	**Group A soils: relict point bar phase.** Undulating plain with numerous crescent shaped channels and ridges. (Point bar deposits of the migrating Ord River - now largely relict). Brown fine sandy loam alluvial soils.
AF	**Group A soils: flooding phase.** Variable deep light textured brown soils (e.g. loamy sands to sandy loams grading very gradually to clay loam). Near Ord River in old meanders and old levees. Subject to flooding.
Ac	**Group A soils: clay subsoil phase.** Variable clay soils. Near Ord River in old meanders and old levees. Clay layers below 1m.
COC4L	**Drainage line/valley floor phase.** Drainage line/valley floor.
COC4G	**Undulating sandstone slope phase.** Stoney soils with sandstone range open woodland.
COK5	**Cockburn lower slopes subsystem.** Gentle lower slopes and minor rises on shale, siltstone or fine-grained sandstone. Shallow loams or loamy duplexes over rock. Stone fragments common in profiles and as mantles.
Chs	**Chunuma sand phase.** Deep brown fine sandy soils on alluvial fans.
D	**Drainage line phase.** Drainage lines. Deep sandy soils on alluvial fans. Swamps and billabongs.
F	**Flood channel phase.** Deep sandy soils. Complex broad flood channel area.
MaW	**Mantinea clay-Winbidji loam complex phase.** Dark grey/brown clay flats. Winbidji loam complex.
Mac	**Mantinea clay phase.** Dark grey/brown clay flats.
MacF	**Mantinea clay, flooding phase.** Dark grey/brown clay flats. Subject to flooding.
Rsl	**Rainyerri sandy loam phase.** Rainyerri sandy loam on gently sloping shale and sandstone hills.
Wi	**Winbidji alluvial loam phase.** Winbidji alluvial loam. Near Ord River in old meanders and old levees.

Proposed Mantinea Development area soils





N

0 1 2 3 4 5

Kilometres

Legend

- Mantinea development area
- Mantinea conservation excision
- Freehold, not Mantinea development area
- River/stream
- Road
- Soil site

See opposite for soil map unit descriptions

Reference
Projection: Transverse Mercator
Datum: Geocentric Datum of Australia 1994
Grid: Map Grid of Australia Zone 52
Source data: Road network and cadastral boundaries supplied by the Western Australian Land Information Authority, 2014.
Soil mapping from DAFWA 2014.
Surface water supplied by Department of Water, 2005.
Project No: DAFWA 2014151
Date: June 2014

Figure 2.1 Soils map of the Mantinea Development area

2.2 Issues affecting capability for irrigated agriculture

2.2.1 Salinity

Information from four datasets in the Mantinea area indicates that the Mantinea clays, and to a lesser extent the Winbidji loams, have subsoil salinity levels of major concern for irrigation. If irrigation were to cause watertables to rise and bring subsoil salts within the root zone of salt-sensitive crops, production may be compromised. This issue requires further investigation to more accurately determine the extent and severity of the issues, and likely management responses to deal with the issue under irrigation. The AEM survey (Lawrie et al. 2010) provides spatial patterns in three dimensions, which can be used to help quantify this risk.

The four datasets — Burvill's 1944 survey, the Mantinea Loop survey (Schoknecht and Grose 1996), ad hoc samples collected by the Ord Development Council in 1994 and the DAFWA analysis of drill spoil from a hydrogeological investigation by the GSWA (Nixon 1996) — are discussed below.

Results from Burvill (1944) survey

The results from Burvill's 1944 survey are summarised in Table 2.1. The locations of the individual sample sites are not known but the number of sites within areas defined by landmarks shown in Figure 2.1 and Figure 2.2 are shown in the table. In the 1940s, soil salinity was determined by an analysis of sodium chloride as a percentage of air-dry soil, with values of 0.2% or higher indicating a likely reduction in crop growth (Teakle 1937). The data indicate that subsoil salinity is more prevalent in the west of the Mantinea Development area where Burvill believed there had been a tidal influence in the formation of the plains.

Results from Mantinea Loop survey (Schoknecht & Grose 1996)

In 1994, while the Mantinea Loop survey was being conducted, a single soil core in a western occurrence of Mantinea clay (site MAN 0017) was taken. The pH and EC results from that core are shown in Table 2.2 and the sampling site location is shown on Figure 2.2 with the 0–2m depth slice from the AEM survey (Lawrie et al. 2010). There are not enough soil sample sites to attempt a statistical correlation between soil salinity and AEM conductivity.

This result reinforces the findings of Burvill (1991) that subsoils in the Mantinea clays in the west of the survey area are often saline.

Results from Ord Development Council samples taken in 1994

In 1994, in response to concerns raised about the salinity of the soils in the area, the Ord Development Council collected several soil samples in the Mantinea area. There are no records of the exact locations of these samples. However, it is known that they were collected from the non-levee plain map units (for example, Mac, MaW, MaF) (N Schoknecht 2014, pers. comm. 18 June). Results of salinity analyses performed on these samples show that the subsoils (50–150cm) at three of the eight sites were moderately to highly saline (Table 2.3).

Table 2.1 Salinity of Mantinea clay and Winbidji loam map units. The sites with a salinity risk are in bold (source: Burvill 1991)

Chloride as sodium chloride % of air-dry soil	Number of sites 0-30cm	Number of sites 30-90cm	Number of sites 90-180cm	Number of sites >180cm
Mantinea clay				
East of the Bend of the Ord River (8 sites)				
0.02 and less	6	8	6	4
0.03–0.2	0	0	2	1
0.2–0.5	0	0	0	0
>0.5	0	0	0	0
Bend of the Ord River to Salt Water Creek Crossing (7 sites)				
0.02 and less	2	4	0	0
0.03–0.2	0	1	2	3
0.2–0.5	0	**1**	**2**	**2**
>0.5	0	0	**1**	**1**
West of Salt Water Creek Crossing (6 sites)				
0.02 and less	3	1	0	0
0.03–0.2	0	3	0	0
0.2–0.5	0	**2**	**2**	**4**
>0.5	0	0	**4**	**1**
Winbidji loam				
Mantinea Creek to Salt Water Creek Crossing (9 sites)				
0.02 and less	3	6	6	6
0.03–0.2	0	2	0	0
0.2–0.5	0	0	0	0
>0.5	0	0	0	0
West of Salt Water Creek Crossing (4 sites)				
0.02 and less	1	0	0	0
0.03–0.2	0	**1**	0	0
0.2–0.5	0	0	**2**	**2**
>0.5	0	0	0	1

Table 2.2 pH and EC results for site MAN 0017; see Figure 2.2 for location. The colour codes for salinity ratings match those used in Figure 2.2.

Depth (cm)	pH 1:5 water	EC 1:5 water (mS/m)	ECe* (mS/m)	Salinity rating*
0–5	6.6	13	105	Non-saline
25–30	8.3	6	49	Non-saline
70–75	8.6	34	275	Slightly saline
140–150	8.1	153	1238	Highly saline

* Estimated using method and ratings described in Moore (1998).

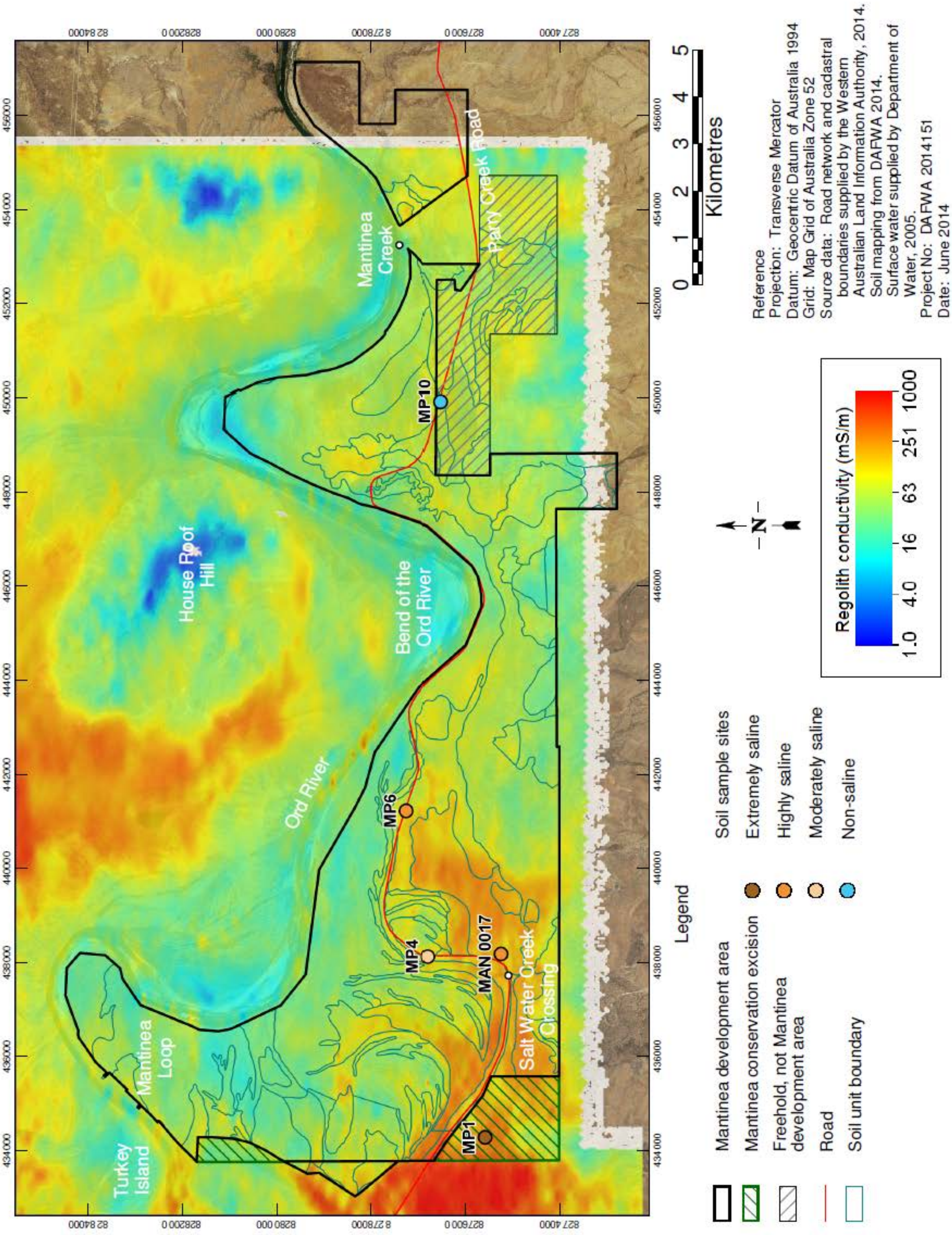


Figure 2.2 Salinity ratings for the 0–3m soil samples from selected GSWA bores and soil survey site MAN 0017, and regolith conductivity for the 0–2m depth slice from the Mantinea AEM survey (Lawrie et al. 2010). Salinity rating for site MAN 0017 relates to the 140–150cm depth interval

Table 2.3 Results of salinity analyses on soil samples collected from non-levee plain soil units on the Mantinea Development area in 1994 by the Ord Development Council (sample locations not known). The colour codes for salinity ratings match those used in Figure 2.2.

Site number	Depth (cm)	EC 1:5 water (mS/m)	ECe* (mS/m)	Salinity rating*
MAN 0101	0–30	8	65	Non-saline
	30–70	46	372	Slightly saline
	70–150	180	1456	Highly saline
MAN 0102	0–10	11	89	Non-saline
	10–40	4	32	Non-saline
	40–100	6	49	Non-saline
MAN 0103	0–10	10	81	Non-saline
	10–40	14	113	Non-saline
	40–80	78	631	Moderately saline
	80–120	98	793	Moderately saline
	120–170	94	760	Moderately saline
MAN 0104	0–10	6	49	Non-saline
	10–30	3	24	Non-saline
	30–60	4	32	Non-saline
	60–100	3	24	Non-saline
MAN 0105	0–10	5	40	Non-saline
	10–40	3	24	Non-saline
	40–70	2	16	Non-saline
	70–120	2	16	Non-saline
MAN 0106	0–30	5	40	Non-saline
	30–90	3	24	Non-saline
	90–120	14	113	Non-saline
	120–180	71	574	Moderately saline
MAN 0107	0–10	11	89	Non-saline
	10–30	6	49	Non-saline
	30–50	3	24	Non-saline
	50–70	5	40	Non-saline
MAN 0108	0–10	9	73	Non-saline
	10–30	6	49	Non-saline
	30–90	4	32	Non-saline
	90–135	10	81	Non-saline

* Estimated using method and ratings described in Moore (1998).

Results from sampling of GSWA bore sites

During 1994, a hydrogeological investigation of the Mantinea Development area was undertaken by the GSWA (Nixon 1996). Samples of drill spoil were bagged at 3m intervals and warehoused in Perth. Sub-samples were taken from the sealed bags for four of the bore sites and field textured and analysed for EC 1:5 water by Schoknecht and Grose (1996). The location of these sites is shown in Figure 2.2 and salinity levels were generally high throughout the entire profiles (Table 2.4).

Table 2.4 Salinity analysis of bore drilling sites (source: Schoknecht & Grose 1996). The colour codes for salinity ratings match those used in Figure 2.2.

Bore	Sample depth (m)	Field texture	EC 1:5 water (mS/m)	ECe* (mS/m)	Salinity rating*
MP1	0–3	Light-medium clay	302	2442	Extremely saline
	3–6	Medium clay	292	2362	Extremely saline
	6–9	Medium clay	227	1836	Extremely saline
	15–18	Sandy clay loam	85	967	Highly saline
MP4	0–3	Light-medium clay	55	445	Moderately saline
	3–6	Light-medium clay	167	1350	Highly saline
	6–9	Coarse sand	28	408	Moderately saline
	9–12	Coarse sand	23	335	Slightly saline
	12–15	Weak loamy coarse sand	47	684	Moderately saline
	15–18	Weak loamy coarse sand	43	626	Moderately saline
MP6	0–3	Light-medium clay	165	1335	Highly saline
	3–6	Light-medium clay	170	1375	Highly saline
	6–9	Light-medium clay	117	946	Highly saline
	9–12	Light-medium clay (sandy)	112	906	Highly saline
	12–15	Light-medium clay (sandy)	65	526	Moderately saline
MP10	0–3	Light clay	18	146	Non-saline
	3–6	Light-medium clay	33	267	Slightly saline
	6–7.5	Light-medium clay (coarse sandy)	40	324	Slightly saline

* Estimated using method and ratings described in Moore (1998).

2.2.2 Drainage

Several map units, such as Unit F, are subject to restricted drainage or are cut by surface watercourses during the wet season and are not suitable for irrigated agriculture unless significant drainage works are undertaken. Several drainage lines flow northward onto the Mantinea Development area from a range of hills located to the south. Agricultural development will need to manage the water coming from these drainage systems. The high-resolution digital elevation models from the LiDAR data for the area (Figure 1.2) will be useful to better quantify these risks and inform appropriate planning and management of the areas under irrigation.

2.2.3 Irregular landform

The sandy soils of the Ord River levees are often irregular in relief with numerous ridges and swales. Significant landform modification to prepare the land for development may be needed (see Figure 1.2). Again, the LiDAR data will be useful in quantifying and managing this constraint.

2.2.4 Soil complexity

The soils in the Mantinea area are complex and vary considerably over short distances. This spatial variation and the associated variation in soil properties (for example, abrupt changes from deep sands to clays) will be an important consideration and constraint to development for irrigated agriculture.

3 Groundwater

The GSWA carried out a drilling program on the Mantinea Development area in the mid-1990s, the results of which are presented in several reports, the two most relevant were published by Nixon (1996, 1997). Laws (1993), O'Boy et al. (2001), Lawrie et al. (2010) and George et al. (2011) also summarise the geology, hydrogeology and irrigation impacts of the ORIA and other parcels of land identified as potentially suitable for irrigated agriculture.

The Mantinea Development area was included in an AEM survey aimed at mapping aquifer materials and salinity hazard in the Ord River valley (Lawrie et al. 2010). The report also covered inundation and flood risks for the Mantinea Development area.

3.1 Geology and sediments

The Carlton Plain and Mantinea Development area are underlain by Proterozoic shale and quartz sandstone belonging to the Mendena Formation of the Kimberley Basin (O'Boy et al. 2001). The basement geology differs to the ORIA Stage 1 and 2 areas, which are typically underlain by the Proterozoic Pincombe Inlier (part of the Carr Boyd Group) consisting of siliceous siltstone and fine-grained sandstone, micaceous shale and quartz sandstone (Plumb & Veevers 1971).

Basement in the Mantinea Development area is generally shallow (5–25 metres below ground level, mBGL) and forms a relatively planar surface that dips from east to west (Nixon 1996). Interpretation of the AEM data by Lawrie et al. (2010) confirms regolith thicknesses from boreholes drilled by the GSWA and identifies areas of only modest internal basement relief. AEM-based interpretation of basement indicates a north-westerly increasing depth ranging from 9.5 to 20.3m (Lawrie et al. 2010).

The basement is overlain by marine, estuarine and fluvial sediments. The marine and estuarine sediments consist of basal sands, which fine rapidly upward and are overlain by fluvial silts and clays. This sequence has been incised by the Ord River as it shifted from its previous course (Lawrie et al. 2010). In the west, where the sediments are thickest, silts and clays overlie sands and increasingly coarse gravels with depth. Nixon (1997) reported that gravels intersected in GSWA bores were generally less than 10mm in diameter but gravel as large as 50mm in diameter was intersected immediately above the basement in bore MP4. In the eastern portion of the flat, silty clays overlie the shale basement at shallow depth (Nixon 1996, 1997).

The sands and gravels, associated with modern alluvium and palaeochannels of the Ord River are the most permeable units of the sedimentary sequence. Nixon (1996) produced a map of the likely distributions of the different sedimentary materials, which showed that most of the Mantinea is underlain by gravel aquifers. This map was updated by O'Boy et al. (2001) who maintained the interpretation of widespread gravel beneath the west and northern Mantinea Development area and adjacent Carlton Plain (Figure 3.1).

In contrast, Lawrie et al. (2010) did not interpret or map extensive gravels under the Mantinea Development area. This difference may have been in part because the gravels intersected in GSWA drill holes were intermingled with sands (see Nixon 1997) and also because of their revision of the sedimentary mode of deposition, based on Sonic core drilling of two bores PL1 and PL2 and interpretation of the AEM data. Lawrie et al. (2010) contend that the basal units of the Parry Lagoons

Succession are marine (from fossil evidence) and that the extent of sands (not gravel-dominant fluvial deposits as O'Boy et al. (2001) interpret) within the younger Ord Succession are restricted to the meander plain of the present Ord River.

Lawrie et al. (2010) estimate the thickness of sand aquifer they describe under the Mantinea Development area to be mostly between 5 and 20m. Under the eastern portion of the Mantinea Development area — where O'Boy et al. (2001) postulate the presence of a clay and silt aquitard — they estimate that the aquifer is 5–8m thick and that in the west, the aquifer is 17–20m thick. They report the presence of gravels in bore PL2 (Lawrie et al. (2010), Figure 270, page 302). Their description of the aquifer as sand is likely based on the dominance of sands over gravels in the profile and the partial induration of gravelly sediments, rather than the absence of gravels.

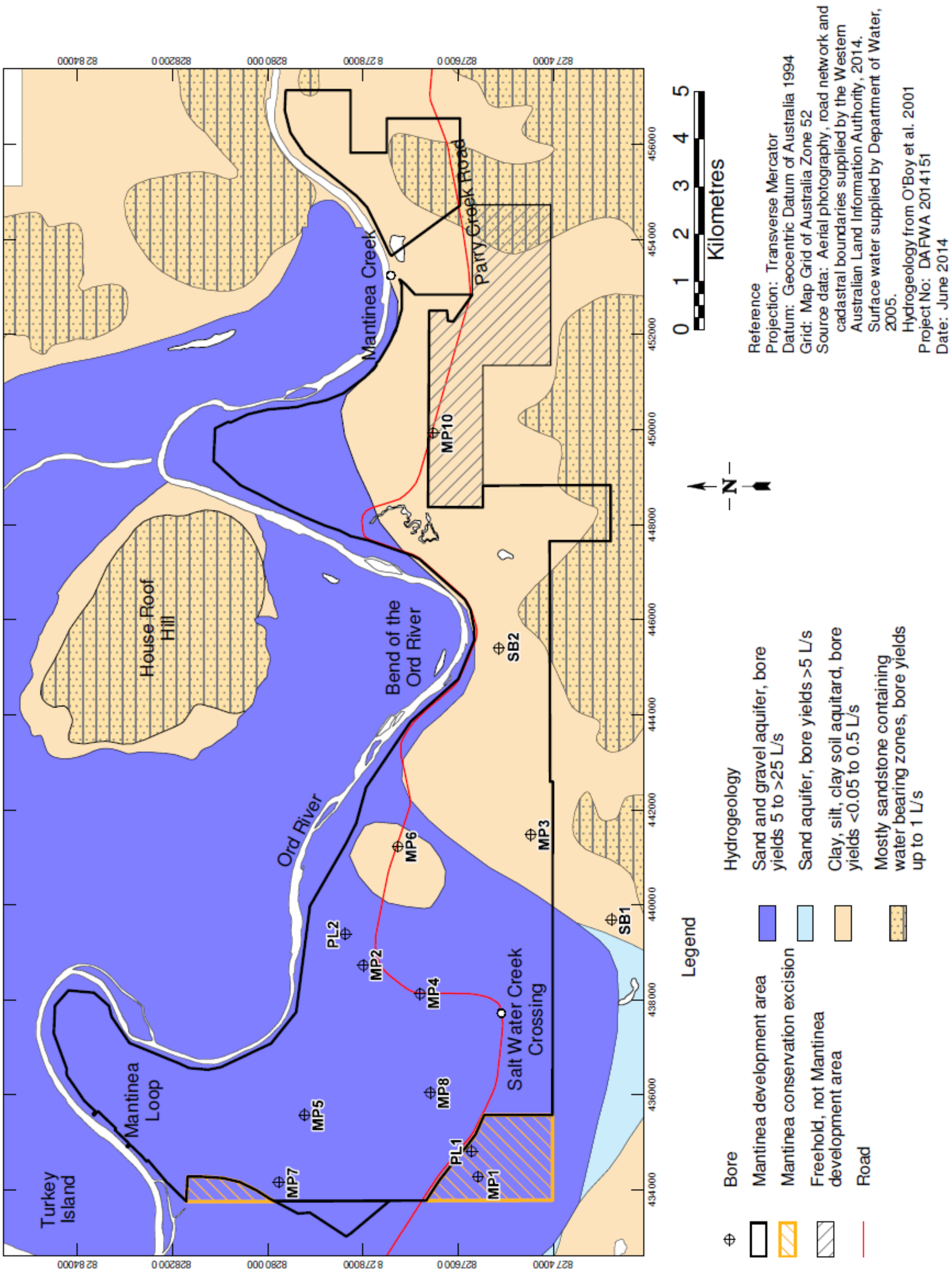


Figure 3.1 Interpreted distributions of sedimentary materials under the Mantinea Development area and Carlton Plain (source: O'Boy et al. 2001)

3.2 Hydrogeology

Table 3.1 provides a summary of the aquifer materials interpreted to be screened in each of the GSWA bores installed in the Mantinea Development area. Bores PL1 and PL2 of Lawrie et al. (2010), and two stock bores located and sampled during field reconnaissance in June 2014, are also included. It is assumed that the stock bores are screened in the sediments and into the fractured basement, though this is not confirmed. Groundwater level trend and water quality data collected by the Department of Water (DoW) and by DAFWA during 2014 are also summarised.

3.2.1 Groundwater levels

Figure 3.2 and Table 3.1 show that groundwater levels in bores screened in the sediments are between 4 and 7mBGL with stable long-term trends. However, they respond to intense and prolonged wet seasons, such as occurred in 2000, 2006, 2008 and 2011 (Figure 1.3). After these wet periods, groundwater levels rise to be about 2–3m above the dry season minima. Depending on the following wet season, they typically drop to base levels one to two years after the seasonal high. Bore MP10, which is almost 9km east of the other bores and the only bore east of the Bend of the Ord River, was dry on completion and remained so until May 2001, following 1300mm of rainfall over the preceding wet season. After 2001, MP10 had the same response as the rest of the bores but was dry again in November 2005.

Groundwater in the one bore drilled into the Proterozoic basement (MP3) is much deeper than in the sediments. MP3 is on the toe of an alluvial fan emerging from the range of sandstone hills south of the Mantinea Development area. Unlike the other bores, and as demonstrated by the hydrograph in Figure 3.2, it appears to be responding to either long-term rainfall trends or the local impacts of streamflows on the alluvial fan, rather than year-to-year rainfall variability. The available evidence suggests groundwater at this site is hydraulically disconnected from the sediments. Bore MP3 was dry until May 2001 and its groundwater level has remained below 0mAHD despite its rising trend.

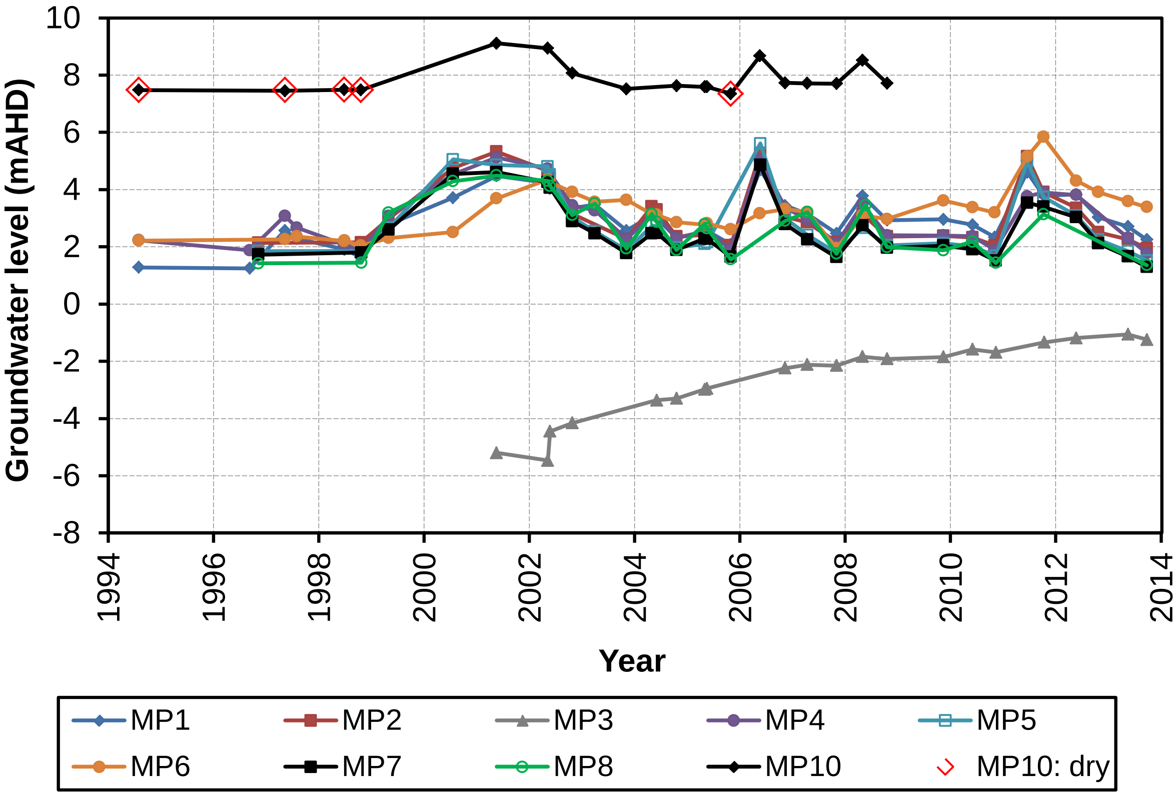


Figure 3.2 Groundwater hydrographs for GSWA bores screened in sediments on the Mantinea Development area and bore MP3 screened in the basement (data from the Department of Water's WIN database)

Table 3.1 Summary of groundwater level, salinity and aquifer material data collected by the GSWA (Nixon 1996, 1997), CSIRO (Lawrie et al. 2010) and at accessible stock bores in the Mantinea Development area

Bore	Depth (m)	Inferred aquifer material	Airlift yield (kL/d)	Last TDS (mg/L)	Salinity category	Last SWL* (mBGL)	SWL trend	SWL range (m)
Screened in sediments								
MP1	16	sands, 9–14mBGL	72	28 914	saline	-4.2	stable	3.4
MP2	24	coarse gravels, 3–20mBGL	86	4 856	brackish	-6.8	stable	3.4
MP4	19	sands, 8–19mBGL	115	10 181	saline	-6.1	stable	3.3
MP5	24	sands and gravels, 5–19mBGL	115	8 979	saline	-6.8	stable	4.1
MP6	13	sands, 7–8mBGL	2	15 738	saline	-6.5	stable	3.9
MP7	28	sands and gravels, 9–17mBGL	11	16 531	saline	-6.2	stable	3.6
MP8	15	sands and gravels, 2–13mBGL	69	13 603	saline	-5.3	stable	3.1
MP10	7	clayey silt, 0.6–6.6mBGL		1 238	marginal	-6.4	stable	1.6
PL1	16	pebbly clay and marine sands, 5–11mBGL		3 357	brackish			2.6
PL2	13	fluvial gravels over marine sands, 8–13mBGL		2 225	brackish			5.6
Stock bore 1		assumed sediments and basement		768	marginal			
Stock bore 2		assumed sediments and basement		884	marginal			
Screened in basement								
MP3	16	shale, 10–16mBGL		894	marginal	-10.7	rising	5.1

* Static water level (SWL) is the groundwater depth below ground level.

3.2.2 Groundwater flow direction

O’Boy et al. (2001) contoured groundwater heads for both the Mantinea Development area and Carlton Plain and the results indicated that east of the Bend of the Ord River, groundwater flow is towards the river. Further west, groundwater flow is to the north-west with a component towards the river. O’Boy et al. (2001) suggest that local groundwater flow reversal — from the river to the aquifer — would occur on high tides. They do not mention the possibility of flow from the river to the aquifer during high flow events.

Time series data of groundwater levels for bores screened in the sediments west of the Bend of the Ord River were contoured (Golden Software, Surfer™) to determine groundwater gradients. Two gridding algorithms — kriging and minimum curvature — were compared to compensate for the sparse spatial data. Observation periods for which data was available for at least four of the seven bores were then analysed.

Groundwater gradients for the observation periods analysed indicated that groundwater flow directions in the Mantinea Development area vary. For more than half of the occasions for which groundwater levels were analysed, groundwater flow was south-east to north-west, parallel to the stretch of the Ord River between the Bend of the Ord and Mantinea Loop.

Following a wet season, groundwater levels were usually highest in bores closest to the Ord River, implying groundwater flow from the river to the south and the west. No river stage height data was available for the analyses and the bore closest to the river (MP6) is 1060m away, so loss from the river cannot be categorically established or rates of loss calculated. However, in May 2006, following 1358mm of rain between November 2005 and the end of April, groundwater levels in the Mantinea Development area were at their highest recorded levels, and groundwater level data indicates there was groundwater flow from the Ord River to the aquifer.

On some occasions, prior to a wet season, groundwater gradients indicate flow from the south-east to the north-west with a component towards the Ord River. On only one occasion, in May 2008, was south to north flow directly towards the river implied by the available data.

Before the construction of the Ord River Dam in 1972, the river overtopped its banks and flooded large areas of the Mantinea Development area and Carlton Plain about one year in eight (Burvill 1991). Under these conditions, loss from the Ord River to the aquifer would be inevitable. Completion of the Ord River Dam has reduced the seasonal variability of the flow of the river. Wet season peak flows have decreased significantly and dry season flow is now maintained (O’Boy et al. 2001). There is insufficient spatial information on groundwater levels to assess the impact of these changes on the interaction between the river and the aquifer.

3.2.3 Groundwater salinity

Figure 3.3 shows time series of groundwater salinity, as TDS, for the bores in the Mantinea Development area. When laboratory-determined TDS data were not available, TDS was calculated from field measured EC data, using a conversion factor of 6.1, which was determined by regression from Weaber Plain data by Lillicrap et al. (2011). The calculated values are broadly consistent with laboratory-determined values. The two stock bores do not have time series data because they were sampled only once.

Groundwater salinities in the sediments are highly variable (Table 3.1, Figure 3.3). The most recent observations ranged from fresh (768mg/L) at stock bore 1 to 83% of seawater salinity at MP1 (28 900mg/L). The groundwater salinity at MP10, east of the Bend of the Ord River, is significantly lower than that at most of the bores to the west.

While there does not appear to be any temporal relationship between the groundwater salinities and the groundwater levels at individual bores, there is a spatial relationship between TDS and AEM EC around the boreholes (Figure 3.4). Bores with the highest TDS are typically associated with the highest regolith conductivity, which is dependent on regolith material and water content as well as salt storage.

The distribution of bores in the Mantinea Development area is skewed towards areas of high regolith conductivity (Figure 3.4). However, groundwater salinities in the area are still significantly higher than in the Ivanhoe and Weaber plains, where irrigation development has or will soon take place. Table 3.2 summarises the ranges of groundwater salinity values in the Mantinea Development area in relation to the Ivanhoe and Weaber plains. The minimum groundwater TDS in the Mantinea Development area is 770mg/L, whereas it is less than 200mg/L in all the other hydrogeological settings for which data are available. The average groundwater TDS in the Mantinea Development area is 2.4 times the average TDS in the Weaber palaeochannel, despite the Weaber data being influenced by three observations of TDS values over 10 000mg/L in areas where groundwater salinities are influenced by thin saturated zones over the highly saline Milligans Formation basement.

Groundwater in the basement, as indicated by bore MP3, is significantly fresher than that observed in most bores screened in the sediments, ranging from marginal to brackish (600–3000mg/L) (Figure 3.3).

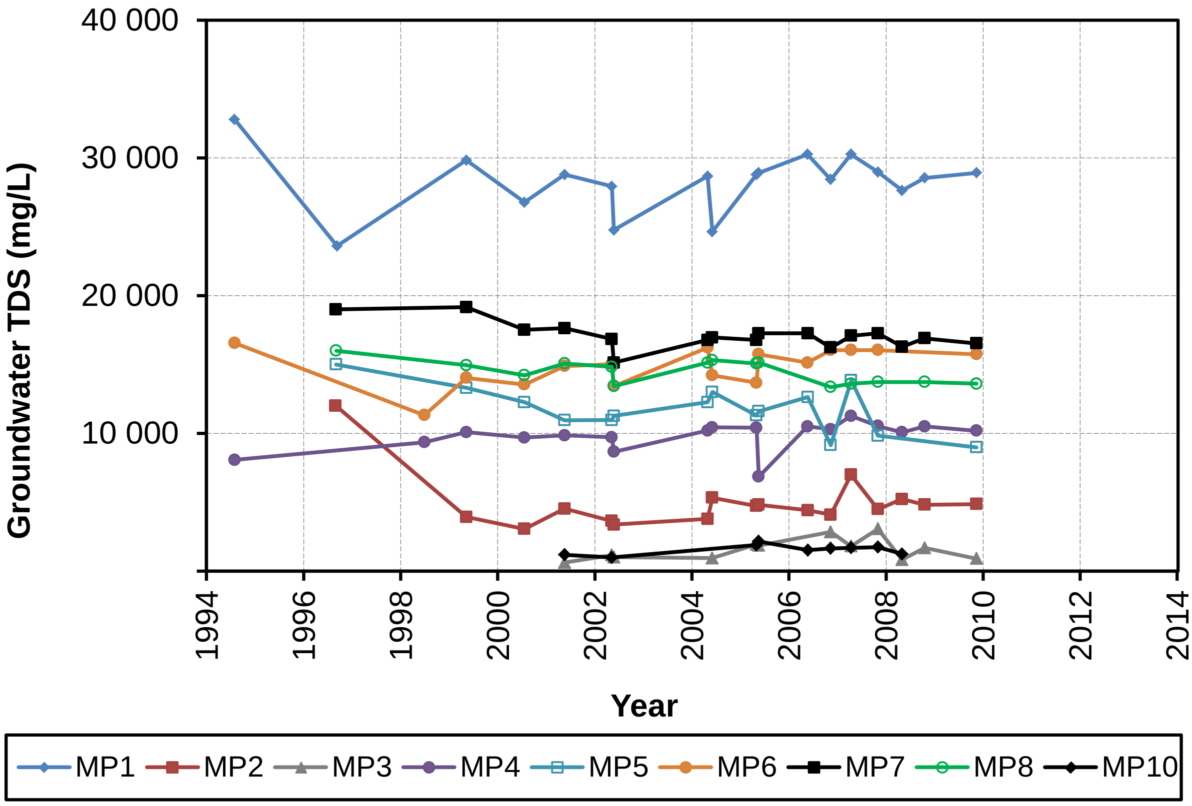


Figure 3.3 Groundwater salinities (TDS) for GSWA bores screened in sediments in the Mantinea Development area, and bore MP3 screened in the basement (data from the Department of Water's WIN database)

Table 3.2 Comparison of recent groundwater qualities in the Mantinea Development area and Ivanhoe and Weaber plains (source: Lillicrap et al. 2011)

Location	Min. TDS (mg/L)	Max. TDS (mg/L)	Average TDS (mg/L)	Number of sites
Ivanhoe: palaeochannel	120	3 500	750	24
Ivanhoe: non-palaeochannel	70	10 000	1 958	16
Weaber: palaeochannel	190	17 000	3 708	9
Weaber: non-palaeochannel	90	11 000	1 922	9
Mantinea: sediments	770	28 900	8 940	12

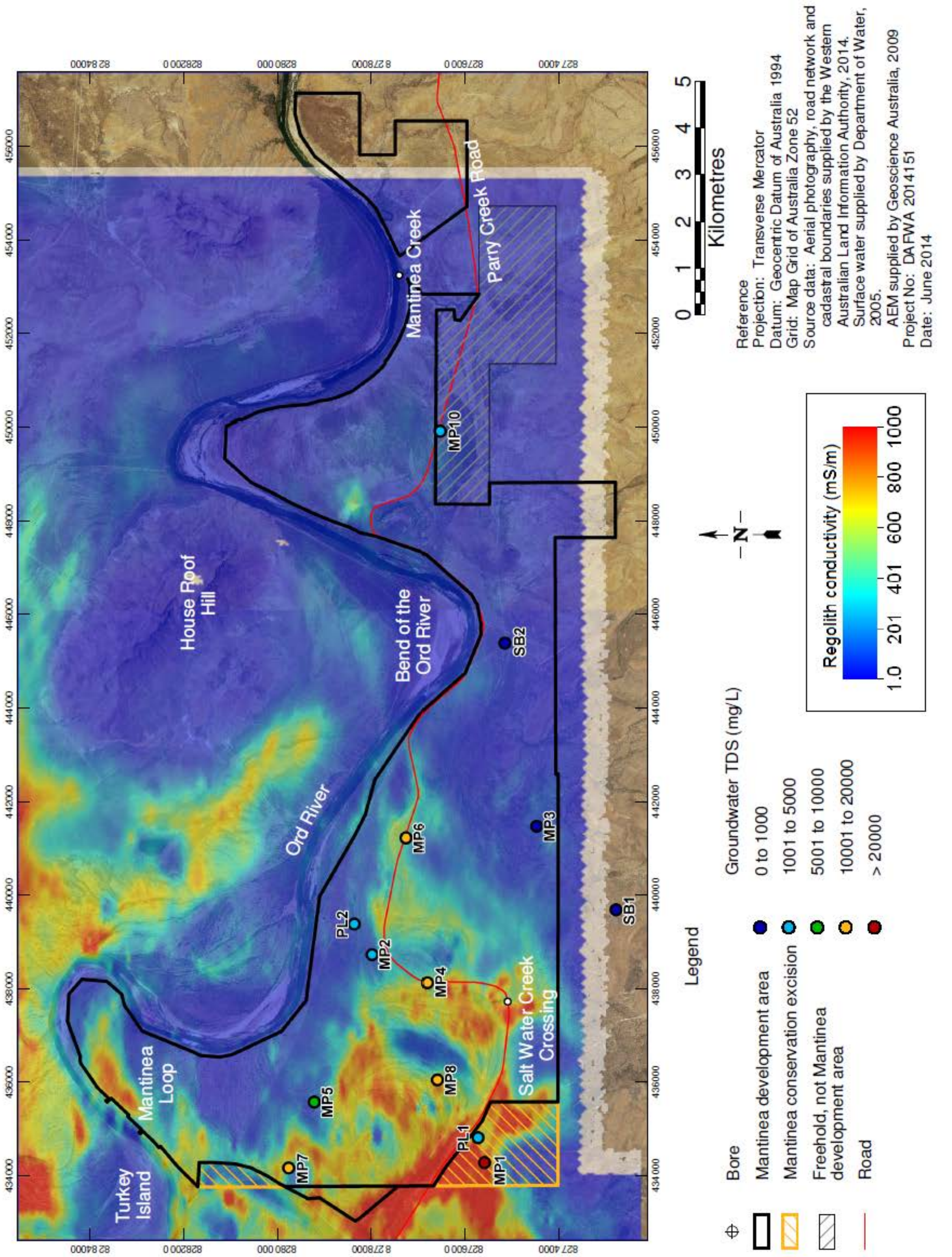


Figure 3.4 Groundwater TDS and regolith conductivity for the 6.7–9.5m depth slice, as determined by the Mantinea AEM survey (Lawrie et al. 2010)

4 Discussion

The capability for irrigated agriculture in the Mantinea area is defined by a range of variables. Of those related to agricultural risk, excess soil salinity and related issues of waterlogging and flooding are most likely to impact the Mantinea Development area. Other factors affecting agricultural production, such as irrigation design, infrastructure, power and transport distance to Kununurra and Wyndham, are not considered here.

4.1 Land capability assessment

Land capability assessment in WA is similar to stage two suitability assessment described in FAO (1976). The term ‘land resource suitability’ is now commonly used in Australia, but because of the prevailing use of the term ‘land capability’ in WA, it is used in this report (van Gool et al. 2005).

Land capability assessment is linked to a land use. Land that has a high capability for one use may have a low capability for another. In this review, the nominated land use is irrigated agriculture, though the type of irrigation system does influence the capability assessment of the land. For example, sandy permeable soils are well suited to spray, trickle or tape irrigation but not flood irrigation. The land capability assessments presented in Table A1 are therefore of a general nature to indicate which map units are suitable for irrigation.

The other key point in land capability assessments is that they are based on the current condition of the land. An issue, such as poor drainage, could lead to a low capability assessment under current conditions. Addressing the constraint could lead to a more favourable assessment. Alternatively, areas assessed as being of high capability for irrigation under current conditions would receive a lower capability rating if groundwater was to approach the soil surface.

The investigations to date demonstrate several soil and drainage constraints — highly variable soils, a salinity risk, particularly in the west of the development area (Figure 2.2), irregular landforms associated with the levee soils, and proximity to the Ord River to the north.

Using the soil information described in Section 2, preliminary land capability assessment shows that 53% (4796ha) of the 9089ha mapped is capable of irrigation development. A further 32% (2876ha) is possibly capable, pending further investigation, and 15% (1395ha) has a low capability for irrigated agriculture under current conditions (Table A1).

This capability assessment is based on limited, historical data and conditions. The AEM survey indicates that subsoil conductivities are highly variable across the Mantinea Development area. If groundwater was to rise as a result of irrigation, it would constitute a change in conditions and may have a negative impact on land capability, especially for areas with high subsoil salinities, potentially including the well-drained sandy soils, which are currently assessed as having high capability.

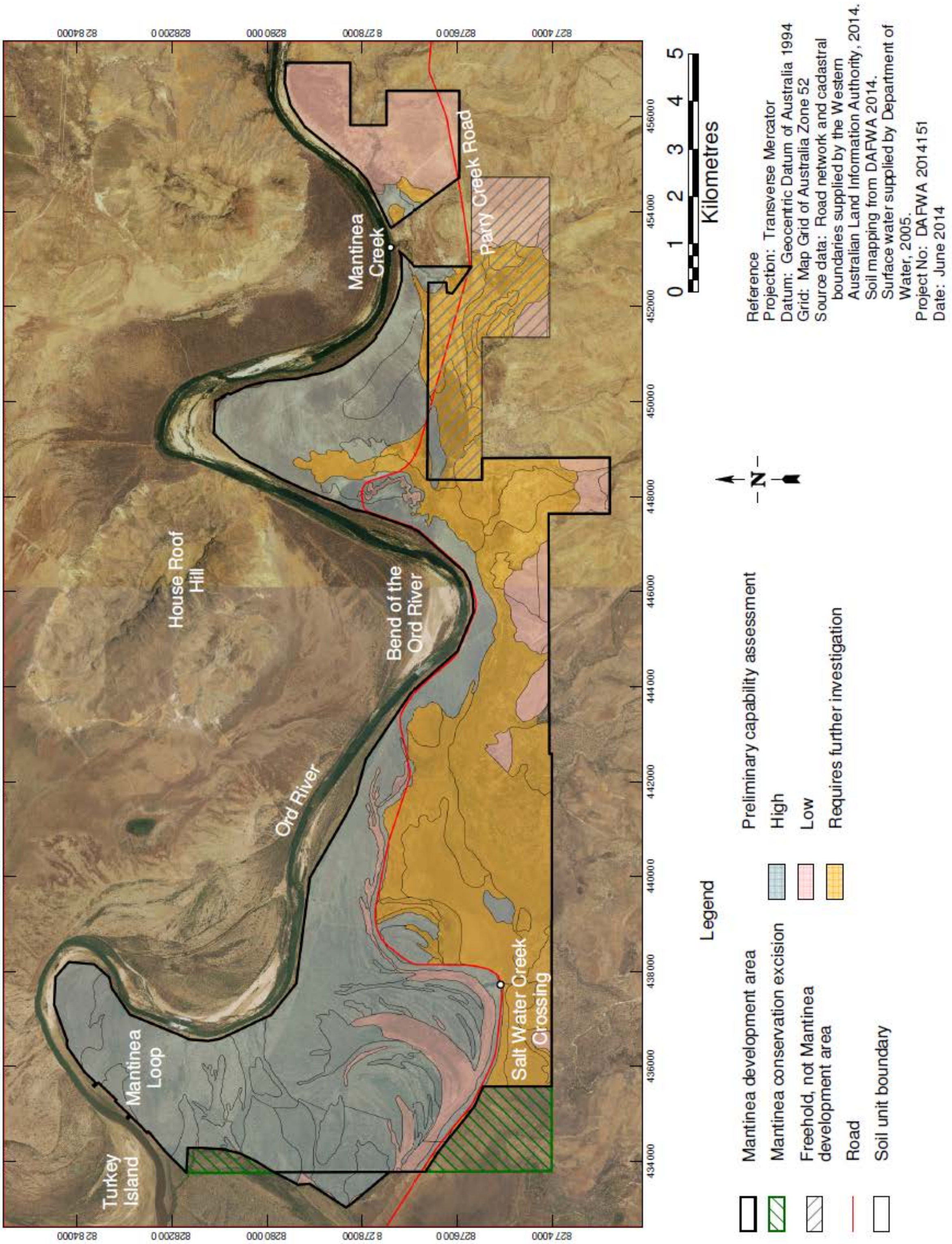


Figure 4.1 Preliminary assessment of the capability for irrigated agriculture in the Mantinea Development area

4.2 Groundwater conditions and risks

Groundwater rise and soil salinity issues have been identified for the Mantinea area, and a salinity hazard assessment was undertaken by Lawrie et al. (2010).

Smith and Price (2009), Lawrie et al. (2010) and George et al. (2011) summarise the factors driving salinity in the ORIA. They report increased groundwater levels of between 5 and 25m, resulting from the combined effects of irrigation and higher than average rainfall conditions experienced after 1993. Significantly, most of the groundwater rise in the ORIA occurred before 1993 and this rise was attributed to clearing and irrigation. Conversely, for most of the Weaber and Knox plains, which was unaffected by the ORIA, no clearing had occurred and increases in groundwater level were attributed to changes in rainfall. Other factors affecting salinity risk are salt storage, irrigation system design and land use (that is, the salinity sensitivity of specific crops).

Monitoring of the widely distributed bores in the Mantinea Development area shows groundwaters are typically within 4–7m of the surface. Groundwater levels rise in the order of 3m after higher than average and prolonged wet season rainfall, but only maintain elevated levels for one to two years, after which they fall back to baseline levels (Figure 3.2). There is also evidence of hydraulic connection between the sedimentary aquifer in the Mantinea Development area and the Ord River. Groundwater discharge to the river appears to dominate, but flow from the river to the aquifer is likely following prolonged periods of high rainfall and high tides.

Groundwater salinity levels in the alluvial sediments ranges from 770 (stock bore 1) to 28 900mg/L TDS (MP1) and have been stable over the monitoring period (Figure 3.3). The highest salinity levels in the alluvium occur in western areas, where most of the bores are located. Connection to the Ord River and associated tidal impacts are the likely cause of the higher salinity in the west.

Lawrie et al. (2010) mapped the distribution of regolith conductivity across the Mantinea Development area and Parry Lagoons area. Maps of conductivity (ranging from 2 to 5m intervals) are available to about 100m depth. Mapped conductivity of 100 to 1000mS/m typically occurs in the upper 2–20m, below which the resistive basement dominates the mapped extent. There is a strong correlation between regolith EC and groundwater TDS (Figure 3.4). . The highest salt stores occur in the far west of the Mantinea area, associated with marine sediments and likely interchange of water with the river during periods of tidal ingress. However, there are also other saline areas apparent in the near surface (e.g., depth layers of 4.2–6.7m and 6.7–9.5m at or near the current watertable) along the western end of Old Wyndham Road in the central part of the Mantinea Development area.

A detailed groundwater model of the aquifer and water balance is required to define the salinity risk and to determine the impact of management actions aimed at mitigating that risk in order to support long-term agriculture. The model will determine the degree to which the dual inputs of regolith EC and groundwater level changes can be used to define salinity risk. The model will need specified aquifer characteristics and knowledge of how variables change, principally those that influence the pre-clearing and post-clearing water balance, and recharge from irrigation.

Notwithstanding the lack of a model, available data and experience in the ORIA and Goomig areas indicate that where the regolith salt storage is high, has shallow, saline groundwater and is remote from discharge areas, such as the Ord River, management options to prevent waterlogging and salinity will be essential.

Such options, including aquifer pumping, appear to be feasible according to the results of bore tests (Nixon 1996, 1997) and analysis of groundwater responses to extended periods of above-average rainfall and the lack of long-term trends in groundwater levels. Together, they imply permeability and connectivity exists within the sediments to enable aquifer drainage to the Ord River. However, as noted above, these baseline conditions will change once the water balance adjusts to clearing and irrigation.

4.3 Proximity to Ord River

The Ord River forms an irregular northern boundary to the Mantinea Development area. A sufficient buffer between any irrigated development and the river will need to be maintained and this may impinge on some of the levee soil units.

The hydraulic connection between the Mantinea sedimentary aquifer and the Ord River implied by the available groundwater data raises the possibility of a nutrient and chemical export risk to the river.

5 Conclusions

Combining the data from available detailed soil surveying and regional-scale land system mapping reveals that of the 10 000ha proposed Mantinea Development area, 4796ha (53%) has a potentially high capability for irrigated agriculture. Another 2876ha (32%) is potentially capable but requires further investigation and 1395ha (15%) of the area has low capability for irrigation (Figure 4.1). This assessment should be viewed as preliminary in nature.

Work to further assess the risks for soils classified as having high capability or requiring further investigation is needed as part of the development process. This work would include soil mapping and chemistry at a fine spatial scale, which would be supported by the available LiDAR and AEM data. Specifically, this work should include soil sampling in areas mapped as requiring further investigation (Figure 4.1) and high capability soils overlying areas of high AEM conductivity in the near surface (Figure 2.2).

Groundwater in the Mantinea Development area is shallow and of variable salinity. The groundwater responses to seasonal rainfall indicate a moderate level of permeability, connection to the Ord River and probably contributions from the river to the aquifer at some times. Groundwater discharge to the Ord River may limit groundwater rise during the dry season but it constitutes a risk of nutrient and chemical leaching to the river.

The available data and model predictions on the Ivanhoe and Weaber plains suggest that groundwaters are likely to approach the land surface under irrigation in some areas, thereby reducing the land capability. Remediation to prevent soil salinisation and waterlogging in these areas will be needed.

The most appropriate tool to determine the degree of intervention needed to keep groundwaters below the critical level is a numerical groundwater model that incorporates the available quantitative data on aquifer conditions and water quality. The groundwater model should be supported by additional drilling and groundwater monitoring specifically designed to identify if and when the Ord River contributes water to the aquifer in the Mantinea Development area, and the salinity of groundwater in the Mantinea Loop and other western areas likely to be affected by tidal impacts.

6 Recommendations

This report compiles the available data on land capability and water-related risks for the Mantinea Development area. The following recommendations are offered as a means to supplement and improve the interpretation of the available data, to support the development of sustainable agriculture and underpin regulatory assessments.

Soils investigations

Fine scale soil surveying of portions of the Mantinea Development area is recommended in areas that:

- are identified in this report as requiring further investigation (Figure 4.1) to achieve a scale of 1:5000, which is recommended for irrigation development (McKenzie et al. 2008)
- are identified as having potential resource risks, such as shallow watertables, particularly those areas where the AEM indicates high subsoil conductivity (Figure 2.2), shallow basement, or similar constraints.

Water-related investigations

A targeted drilling program is recommended to:

- improve the knowledge of the distribution, hydraulic properties and aquifer gradient of sediments, especially in areas defined at potential risk of shallow watertables
- assess the connectivity between the sedimentary aquifer and the Ord River, particularly during flood and tidal phases, as a means of quantifying recharge and the impact of groundwater drainage of the Mantinea Development area
- determine the connectivity between the fractured rock and alluvial soils in areas proposed for agriculture, especially in western areas at risk of waterlogging.

Logging river stage and salinity at several locations along the Mantinea reach is also recommended to help quantify the connectivity between the Ord River and the sedimentary aquifer.

Appendix A Soil units and capability for irrigated agriculture

Table A1 Summary of soil units and preliminary assessment of capability for irrigated agriculture. See Figure 2.1 for the soils map

Map unit label	Map unit name	Map unit description	Area (ha)	Comments and capability for irrigated agriculture
Mantinea Flat – Goose Hill soil mapping (Burvill 1991)				
A	Group A soils: old levee and meander phase	Variable deep light-textured brown soils (e.g. loamy sands to sandy loams grading very gradually to clay loam). Near Ord River in old meanders and old levees.	2726	High capability for spray, trickle or drip irrigation. The undulating and irregular surface topography in some areas may cause issues for irrigation design.
Ac	Group A soils: clay subsoil phase	Variable clay soils. Near Ord River in old meanders and old levees. Clay layers below 1m.	131	High capability for spray, trickle or drip irrigation. The undulating and irregular surface topography in some areas may cause issues for irrigation design.
AF	Group A soils: flooding phase	Variable, deep light-textured brown soils (e.g. loamy sands to sandy loams grading very gradually to clay loam). Near Ord River in old meanders and old levees. Subject to flooding.	412	High capability for spray, trickle or drip irrigation with appropriate drainage management. The flood risk identified by Burvill (1991) in the 1944 survey has been modified with the construction of Lake Argyle in the 1970s.
Chs	Chunuma sand	Deep, brown, fine sandy soils on alluvial fans.	400	Soils are related to the cockatoo sands and have limited capability for spray or drip irrigation. Wet season waterlogging may be a constraint given their flat topography and proximity to streams and hills. Requires further investigation.
D	Drainage line phase	Drainage lines. Deep sandy soils on alluvial fans. Swamps and billabongs.	441	Low capability because of poor drainage.

Map unit label	Map unit name	Map unit description	Area (ha)	Comments and capability for irrigated agriculture
F	Flood channel phase	Deep sandy soils. Complex, broad flood channel area.	1403	Low capability because of poor drainage. If this constraint is addressed, the land capability rating will improve and hence this unit requires further investigation.
Mac	Mantinea clay phase	Dark grey/brown clay flats. Occurs on floodplain, deltaic and tidal plain deposits with soils similar to Cununurra Clay (Ivanhoe Plain).	820	High capability for irrigation where salinity is not an issue; however, saline subsoils occur in western parts of the Development area. Many areas have moderate to high risk of salinisation under irrigation and this unit requires further investigation.
MacF	Mantinea clay, flooding phase	Dark grey/brown clay flats. Subject to flooding.	184	Low to moderate land capability. Soils as for Mantinea clay phase, although more poorly drained, with affinities to the Aquitaine clays of Ivanhoe Plain. Moderate to high risk of salinisation under irrigation and this unit requires further investigation.
MaW	Mantinea clay-Winbidji loam complex phase	Dark grey/brown clay flats. Winbidji loam complex. Areas of soil complexity, including patches of Mantinea Clay with strips or tongues of alluvial soil like the Winbidji loam.	724	Potentially capable of irrigation, although the soil complexity will complicate management. This unit requires further investigation.
Rsl	Rainyerri sandy loam	Rainyerri sandy loam on gently sloping shale and sandstone hills.	164	Low capability for irrigated agriculture because of shallow bedrock (shale and fine-grained sandstone) at around 450mm depth, gentle slopes prone to erosion and a frequently rough and stony surface.
Stony	Gentle sandstone slopes	Stony soils.	114	Low capability for irrigated agriculture because of high stone content, shallow nature of soils, and erosion risk because of the slope.

Map unit label	Map unit name	Map unit description	Area (ha)	Comments and capability for irrigated agriculture
Wi	Winbidji loam	Winbidji alluvial loam. Near Ord River in old meanders and old levees. Brown loams or clay loams which merge into clay at depth.	425	High capability for irrigated agriculture.
Mantinea Loop soil mapping (Schoknecht & Grose 1996)				
A1	Group A soils: flat plain phase	Flat to gently undulating plain with numerous small depressions and ridges. Brown, fine sandy loam alluvial soils.	636	High capability for spray, trickle or drip irrigation.
A2	Group A soils: relict flood channel phase	Undulating plain with numerous distinct ridges, channels and depressions (relict Ord flood channels). Brown, fine sandy loam alluvial soils.	203	High capability for spray, trickle or drip irrigation. The undulating and irregular surface topography may cause issues for irrigation design, and significant soil levelling may be required.
A3	Group A soils: relict point bar phase	Undulating plain with numerous crescent-shaped channels and ridges (point bar deposits of the migrating Ord River — now largely relict). Brown, fine sandy loam alluvial soils.	149	High capability for spray, trickle or drip irrigation. The undulating and irregular surface topography may cause issues for irrigation design, and significant soil levelling may be required.
Ord land unit mapping (Schoknecht et al. 2005)				
COC4L	Drainage line/valley floor phase	Drainage line/valley floor.	73	Low capability for irrigated agriculture because of poor drainage.
COC4G	Undulating sandstone slope phase	Stoney soils with sandstone range open woodland.	86	Low capability for irrigated agriculture because of shallow bedrock (shale and fine-grained sandstone) at around 450mm depth, gentle slopes prone to erosion and a frequently rough and stony surface.

Map unit label	Map unit name	Map unit description	Area (ha)	Comments and capability for irrigated agriculture
COK5	Cockburn lower slopes subsystem	Gentle lower slopes and minor rises on shale, siltstone or fine-grained sandstone. Shallow loams or loamy duplexes over rock. Stone fragments common in profiles and as mantles.	823	Low capability for irrigated agriculture because of shallow bedrock (shale and fine-grained sandstone) at around 450mm depth, gentle slopes prone to erosion and a frequently rough and stony surface.
Lower Ord Ramsar site (Parry Lagoons) mapping (Hale 2008)				
riv3	Group A soils: old levee and meander phase	Variable, deep, light-textured brown soils (e.g. loamy sands to sandy loams grading very gradually to clay loam). Near Ord River in old meanders and old levees.	160	High capability for spray, trickle or drip irrigation. The undulating and irregular surface topography in some areas may cause issues for irrigation design.
riv5	Drainage line phase	Winbidji alluvial loam. Near Ord River in old meanders and old levees.	1	Low capability for irrigated agriculture because of poor drainage and proximity to Ord River.

List of shortened forms

Phrase or symbol	Full title
AEM	airborne electromagnetics
DAFWA	Department of Agriculture and Food, Western Australia
DoW	Department of Water
EC	electrical conductivity
ECe	electrical conductivity of a saturated extract taken from a soil sample
EIA	environmental impact assessment (Western Australia)
FAO	Food and Agriculture Organization of the United Nations
GSWA	Geological Survey of Western Australia
ha	hectare
kL/d	kilolitres per day
km	kilometre
L/s	litres per second
LiDAR	Light Detection and Ranging, or Light and Radar
m/y	metres per year
mAHD	elevation in metres, relative to the Australian height datum
mBGL	depth, metres below ground level
mg/L	milligrams per litre
mS/m	milliSiemens per metre (a unit of electrical conductivity)
ORIA	Ord River Irrigation Area
SWL	static water level
TDS	total dissolved solids

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