Sustainable Soils Management Pty Ltd
ACN 105 201 581

5 Lawson St,
P.O. Box 130,
Warren, NSW. 2824.
Ph (02) 68473367
Fax (02) 68473401

Groundwater Levels beneath Mantinea and Carlton Plain and Implications for Irrigation Development.

Prepared for: **Kimberley Agricultural Investments Pty Ltd**

January, 2017

Prepared by: **Dr Pat Hulme**

Background

Secondary salinisation of irrigated land occurs when groundwater containing salts is drawn to the soil surface by capillary rise and evaporates, leaving salts at the surface (Figure 1).

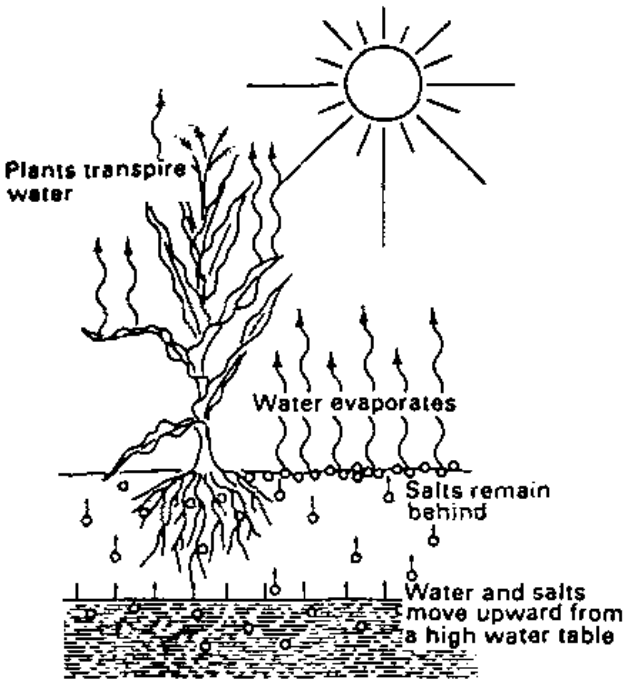


Figure 1. Diagram of processes causing surface soil salinity (from Brouwer *et al.,* 1985).

The speed of water movement to the surface is controlled by depth to the water table, which changes with the balance of water flows in and out of the underlying formation (Figure 2) and soil porosity.

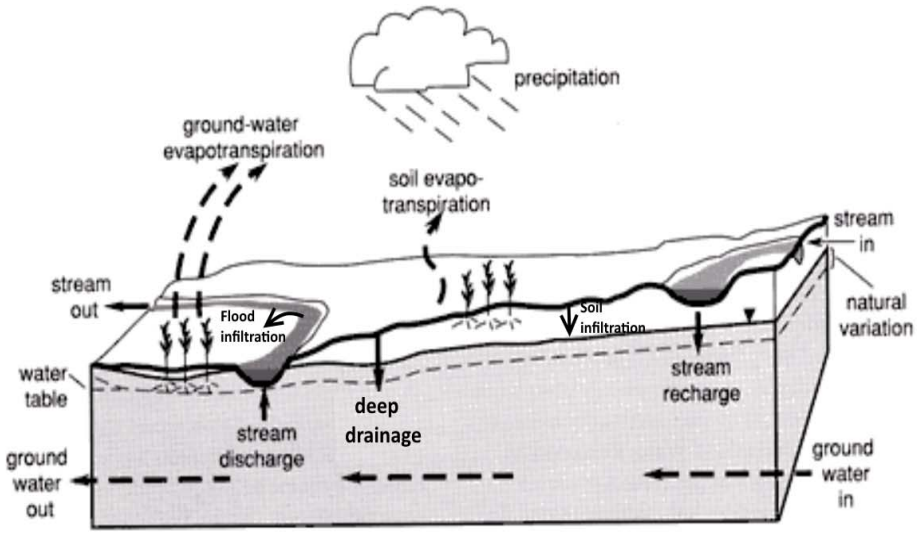


Figure 2. Schematic of inflows and outflows for a regional groundwater balance (modified from Buchanan and Buddemeier, 1993).

Inflows to a typical groundwater balance (Figure 2) are:

- Infiltration through the soil surface
- Stream recharge
- Groundwater inflow.

Outflows from a typical groundwater balance (Figure 2) are:

- Transpiration + soil evaporation (evapotranspiration)
- Stream discharge
- Groundwater outflow.

Deep drainage (Figure 2) is the difference between infiltration through the soil surface and evapotranspiration.

At equilibrium, groundwater inflows are equal to groundwater outflows, although groundwater will rise and fall with short-term and long-term rainfall variation.

Change in landuse from rain-fed perennial vegetation to irrigated annual cropping is associated with greater increases in infiltration than evapotranspiration which then results in a shallower water table. Observations in the Ord River Irrigation Area are that the water table rose by around 0.3 to 0.5 metres per year for 40 years (15 to 20 metres in total, Smith *et al.,* 2006). The rise in groundwater resulted from deep drainage beneath the irrigated land of 30 to 50 mm/year given an assumed storage coefficient of 10% (Smith *et al.,* 2003). Deep drainage from the MI channel and recharge from Lake Kununurra have contributed to the large rise in groundwater levels beneath the Ord River Irrigation Area (Figure 3). The rate of rise of groundwater has been mitigated by discharge to the Ord and Durham Rivers and Packsaddle Creek (Figure 3). The rate of discharge has increased as the water table has risen and was similar to the recharge from Lake Kununurra in 1975, and nearly double the recharge from Lake

Kununurra in 2003. The increased infiltration from irrigation and rainfall in 2003 was attributed to a larger area of sugarcane in this season. Note that the groundwater outflow is the smallest component of the post-development balance, being equivalent to between 2 and 5% of the groundwater inflows.

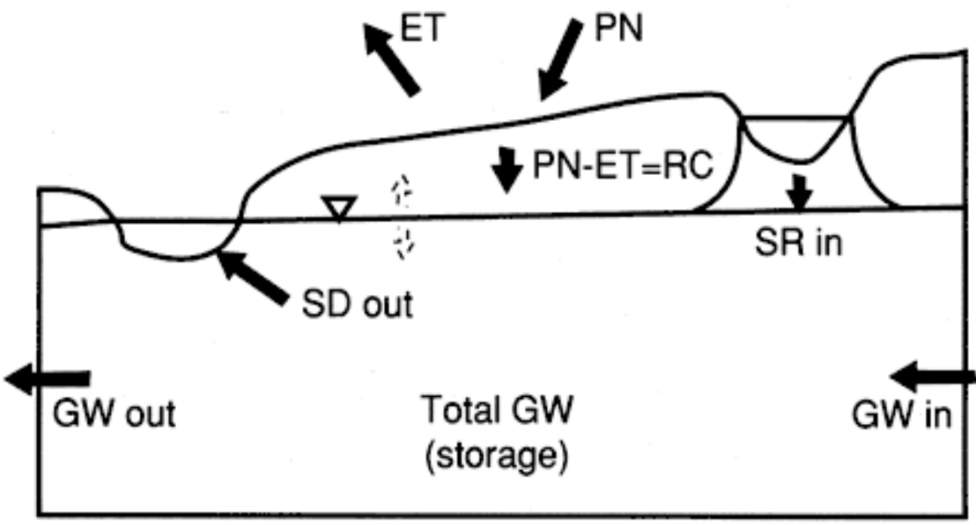


Figure 3. Summary of main components of groundwater balance beneath Ord River Irrigation Area (from Smith *et al.,* 2003).

A crop rootzone water balance for soil in the Ord Irrigation Area indicates that minimal surface salinity develops when the water table is deeper than 2 to 3 m, and that the severity of salinity increases as the water table rises from 2 m deep to 1 m (Ali and Salama, 2003). Ali and Salama (2003) also predicted that surface salinity would be greater under uncropped than cropped conditions. This indicated that maintaining a water table depth greater (deeper than) 2 m is the simplest way of avoiding secondary soil salinisation.

In the simplest terms, the water table can be lowered either by reducing deep drainage and groundwater recharge (Figure 2), by increasing natural groundwater discharge, or by removing some groundwater using deep drains or de-watering wells. These will be discussed below.

Eliminating deep drainage can be achieved by lining all water supply channels and storages combined with irrigation practices that do not result in deep drainage.

Channels can be lined with compacted "clay" or synthetic liners such as plastic or rubber. My experience is that it is relatively straight forward to construct a clay lining that reduces deep drainage, below that of an unlined channel. However, it is much more challenging to construct a clay liner with an infiltration rate of 3 mm/day or less because the construction standards required are more like those used in civil works (e.g. laboratory testing of material then compaction of whole liner to 98% maximum dry density at optimum moisture content which is monitored by an engineer, lining thickness maintained, then channel to remain weed free and not dry and crack) than the standards normally used in construction of irrigation (compact material that appears moist enough with padfoot roller). The alternative synthetic liner is expensive, also requires very high construction

standards, requires protection from wildlife (unless buried), and a high standard of maintenance. Deep drainage from channels can sometimes be reduced substantially by siting channels and storages over parts of the landscape with low potential deep drainage rates.

Reducing deep drainage beneath fields to pre-development rates. This would require a 99.4 to 99.8% reduction in deep drainage in the Ord River Irrigation Area, which Smith *et al.,* (2006) concluded was unlikely to be achievable. Deep drainage beneath surface irrigated fields can be reduced by optimising the duration of irrigation (the flow rate and length of time water runs into each furrow). Dalton *et al.,* (2001) reported that deep drainage could be reduced by as much as 60% in furrow irrigated clayey soil by increasing flow rate and stopping siphons before water reached tail drain end of furrow. In the Ord, Ali *et al.,* (2010) found that irrigation application could be reduced by optimising irrigation scheduling, but deep drainage was not reduced substantially unless the depth of water applied was less than potential crop water use.

The irrigation system could be changed to reduce deep drainage, however field measurements in sugar cane in the Burdekin recorded a reduction in deep drainage of only 36% when comparing drip and furrow irrigation (Bhattarai and Midmore (2015). Bhattarai and Midmore (2015) also measured large deep drainage beneath sprinkler irrigated bananas in leaky soil. One advantage of sprinkler irrigation in areas with a shallow water table is that salt is leached uniformly from the surface since there is less lateral water movement under this system than furrow or drip irrigation.

Groundwater pumping to lower the water table is feasible in selected situations. These are where the aquifer consists of clean gravel and sand, is not close to a source of recharge, and the pumps are placed close enough to dewater the whole area. Smith *et al.,* (2005) found that the radius of influence of dewatering bores in the Ord River Irrigation Area was 1 km, implying that each bore can dewater less than 100 ha. Disposal of water from dewatering groundwater is not an issue if it is of good enough quality that it can be used for irrigation either alone or shandied with river water. However, disposal of saline water can be challenging. Ali *et al.,* (2002) concluded that recycling of groundwater by mixing it with surface water was feasible in 4 of 5 hydrological zones in the Ord River Irrigation Area tested. The water rated as feasible for irrigation had salinity that ranged from a TDS of 580 to 1,460 mg/L, while the water rated as unsuitable had a TDS of 6,200 mg/L.

Drains can be used to intercept shallow groundwater in the rare situation where sediment permeability is adequate (Smith *et al.,* (2006). Subsurface drains can also be used to intercept shallow groundwater.

Unirrigated **trees** have been reported to lower groundwater levels beneath the area planted (Smith *et al.,* (2006). Smith *et al.,* (2006) believes that the effect of trees on groundwater levels is greatest where aquifer transmissivity is low, and that there is likely to be minimal effect of trees on groundwater levels where they are grown over the highly transmissive palaeochannel system.

The factors from the research described above relevant to the proposed irrigation development on Mantinea and Carlton Plain are:

- Secondary salinisation will develop in areas where the water table is shallower than 2 m. The speed of salinisation increases as the water table rises from 2 m.

- Discharge to the river channels is a significant component of the groundwater balance, and may also be significant in the lower reaches around Mantinea and Carton Plain.

- In contrast, lateral groundwater movement parallel to the river channel is likely to be much slower.

- The water table can be lowered by reducing deep drainage beneath the irrigation development. Deep drainage can be reduced by practises such as lining channels, optimising irrigation application through crop selection, and irrigation design and management. However, it is extremely unlikely that these practises will reduce deep drainage to that of undeveloped land.

- The water table can also be lowered by extracting water with dewatering bores, and drains that are designed to fit with soil and aquifer properties. Water extracted in this way may be suitable for irrigation, or may need to be disposed of.

- Unirrigated tree plantings have been found to lower groundwater levels in the immediate vicinity of the trees, but not over large areas around the trees.

So the best scenario for an irrigation development is to locate it in an area where the water table is deeper than 2 m. Then manage this site so that deep drainage is less than the rate at which water can discharge into neighbouring watercourses.

Groundwater Assessment Methods

Current groundwater conditions beneath Carlton Plain and Mantinea and their implications for the proposed irrigation development were assessed in 2 ways. The first was essentially a summary of lithology and the behaviour of shallow groundwater from data for 27 piezometers over the 26,000 ha study area extracted from the Government of Western Australia's Water Information (WIN) database. The second was to select information relevant to Carlton Plain and Mantinea from spatial layers generated by the Ord Airborne Electromagnetics (AEM) project (Lawrie *et al.,* 2010).

Data from the WIN database were processed in the following way:

- The lithology of each layer in each bore was classified into the texture groups of: medium clay (medium, medium heavy and heavy clay), light medium clay, light clay (light clay, silty clay and sandy clay), light soil (clay loam, sandy clay loam, silty clay loam, loam, sandy loam and silty loam), sand (clayey sand, silty sand, sand and gravel) or rock. The simplified lithology was mapped on the site of each test hole.

- Groundwater hydrographs for the period from 1993 to 2014 for 24 of the test holes. No groundwater levels were available for 8327. Only 2 measurements were available for 8333 (Y11) while levels for 11354590 (Y17A) were similar to those for the adjacent bore 8338 and less frequent, so they were not presented. Static Water Level (SWL) values in the database were reduced to ground level by subtracting the height of the measurement point from each value. Values that appeared to be outliers were not removed from the hydrographs, but a check was made that these outliers did not indicate SWL below the bottom of the screen in the piezometer. A comparative line was added to each hydrograph. Rainfall residual mass (yesterday's value + yesterday's rainfall – average daily rainfall) for sites where SWL generally rose over the measurement period. Average river flow over the previous 30 days at Tarrara Bar for sites where the troughs in hydrographs fell to a consistent value. The average river flow was used to indicate periods of prolonged rainfall as short, large rainfall events are less effective in recharging groundwater than consistent rain over weeks or months.
- Three north-south and three east-west transects of groundwater levels reduced to AHD (m above mean sea level) across Mantinea and Carlton Plain for both wet and dry periods were generated to assess the potential of lateral groundwater movement. My understanding of the landscape is not good enough at this stage to generate groundwater surfaces in this dissected flood plain. Average groundwater salinity was calculated from data in the WIN database for 23 of the 27 sites. This salinity was divided into 4 classes on the basis of potential uses for the water. The classes were on the basis of Total Dissolved Solids (TDS) using critical values of DNR (1997) where water with TDS less than 2000 mg/L could be used for irrigating moderately salt tolerant crops (with leaching fraction of 15%) water with TDS between 2,000 and 5,000 mg/L might be suitable for irrigating salt tolerant crops with exemplary management in sand. Water with TDS above 5,000 mg/L is unsuitable for irrigation, and a fourth class of water with salinity, greater than half that of seawater was added since more than half the sites had water that is too salty for irrigation.
- Six north-south cross sections of lithology and conductivity through Mantinea and Carlton Plain were generated by Lawrie *et al.,* (2010). These help to assess the likely properties between the test holes in the WIN database.

The layers selected from the Ord AEM project were: geomorphology, current groundwater depth, potential recharge salt store above the water table and salinity hazard.

Geomorphology was derived from the elevation surface, radiometrics and satellite imagery and divides the area into zones with similar soil formation and hydrological properties (Lawrie *et al.,* 2010).

The depth to groundwater was estimated for July, 2008 by subtracting a surface of groundwater levels at that time from the digital elevation model (DEM) (Lawrie *et al.,* 2010).

The Recharge Potential map shows the estimated thickness and permeability of the least leaky layer in the soil profile (Lawrie *et al.,* 2010).

Salt store in the unsaturated zone was determined from estimates of the depth to groundwater, and the salt concentration in the material above the water table (Lawrie *et al.,* 2010). This salt can be mobilised to cause rootzone salinity.

Lawrie *et al.,* (2010) used a combination of water table depth and the mass of salt stored in the unsaturated zone to estimate the salinity hazard. This is presented in the salinity hazard map for the area subjected to the AEM survey (Figure 4).

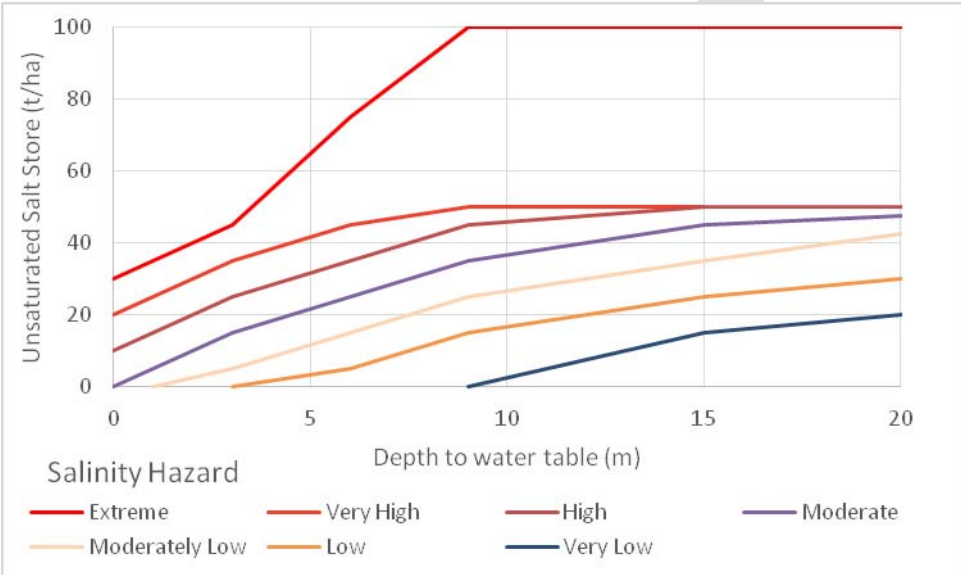
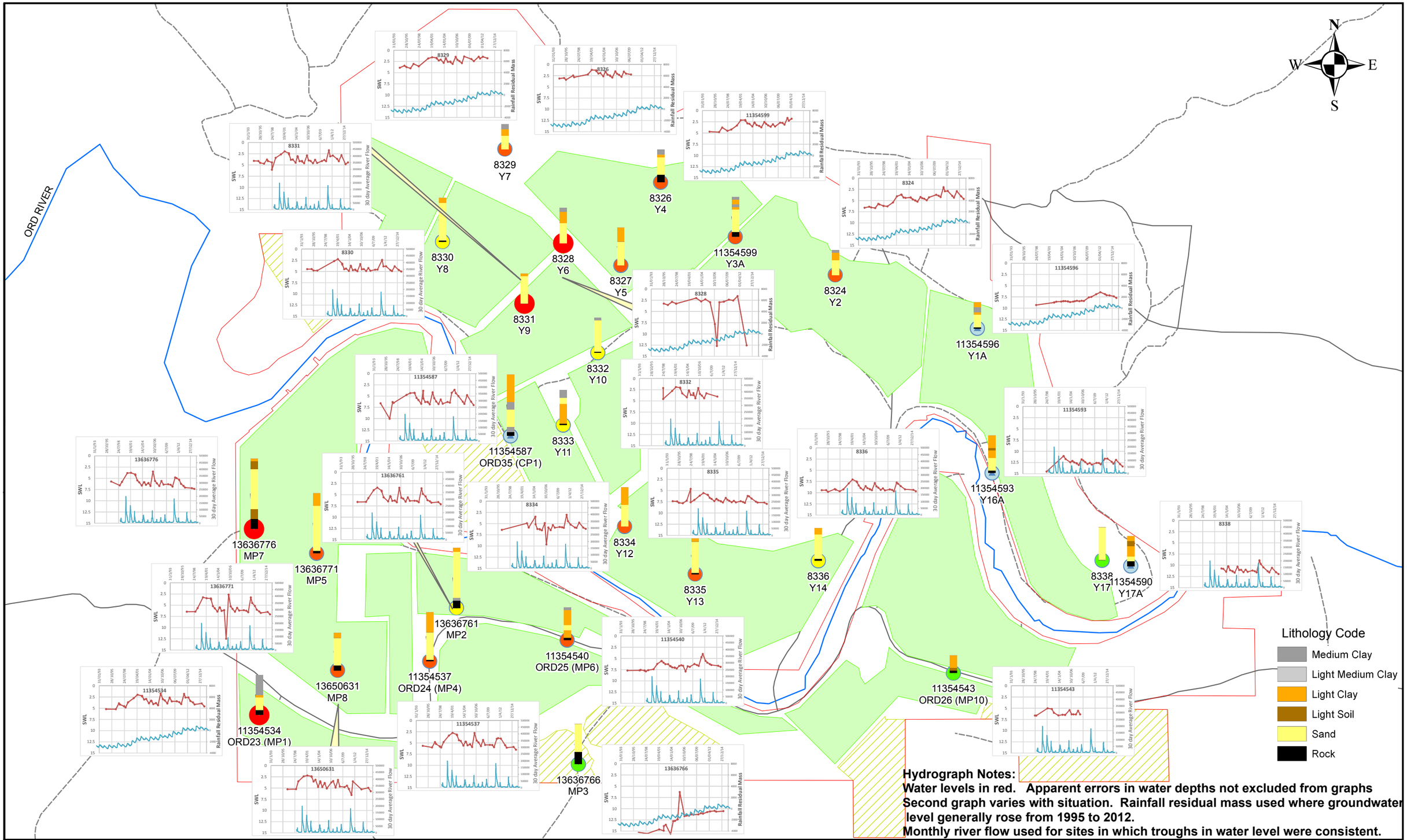


Figure 4. Critical combinations of Depth to water table and unsaturated salt store to estimate salinity hazard (Adapted from Lawrie *et al.,* 2010).

Observations

The **lithology** of the 27 test holes consisted predominantly of a surface clay layer that was 2 to 10 m thick over sand and gravel layer (Map 1) with an average thickness of 9 m. Weathered rock was logged at the bottom of 21 of the 27 holes at depths that varied from 6 to 24 m, with an average depth of 14.5 m. Lawrie *et al.,* (2010) concluded that the sand and gravel layer was a mixture of fluvial (deposited by rivers) and marine origin. They were able to differentiate between these 2 sources and essentially found that the plain beneath Carlton Plain and Mantinea is predominantly a coastal plain into which the Ord River has been inset (Appendix I, Lawrie *et al.,* 2010). The implications of the broad extent of the marine plain and the narrow extent of the alluvial deposits are that the majority of the material would be expected to have a large salt load unless salts have been flushed from the material by lateral groundwater flow.

The **hydrographs** show large variations in which the water levels increase by as much as 3 m in some wet seasons, then fall consistently for as long as 3 or 4 years before rising by as much as 3 m again (Map 1).



Hydrograph Notes:
Water levels in red. Apparent errors in water depths not excluded from graphs
Second graph varies with situation. Rainfall residual mass used where groundwater level generally rose from 1995 to 2012.
Monthly river flow used for sites in which troughs in water level were consistent.

Mantinea and Carlton Plains

Kunnanurra

HydrographTransects

Property Boundary

Piezometers

FarmArea

Proposed Irrigaiton

TimberArea

TDS_SITU

No data

Irrigate moderately salt tolerant

Irrigate salt tolerant crops

Unsuitable for irrigation

>Half seawater salinity

Roads

Principal Road

Secondary Road

Minor Road

Track

Watercourses

Major

0 1 2 3 4

Kilometres

1 cm = 0.8 km on A3

Certification

Draft/Uncontrolled Document
Unless Signed & Dated

Job Code: GW026
Boundaries: KAI
Topography: Geoscience Aus
Groundwater Data: WA WIN database
Contact: Sustainable Soils Management
Phone : (02) 68 473367

Datum: WGS 84
Projection: UTM

SSM Sustainable Soil Management

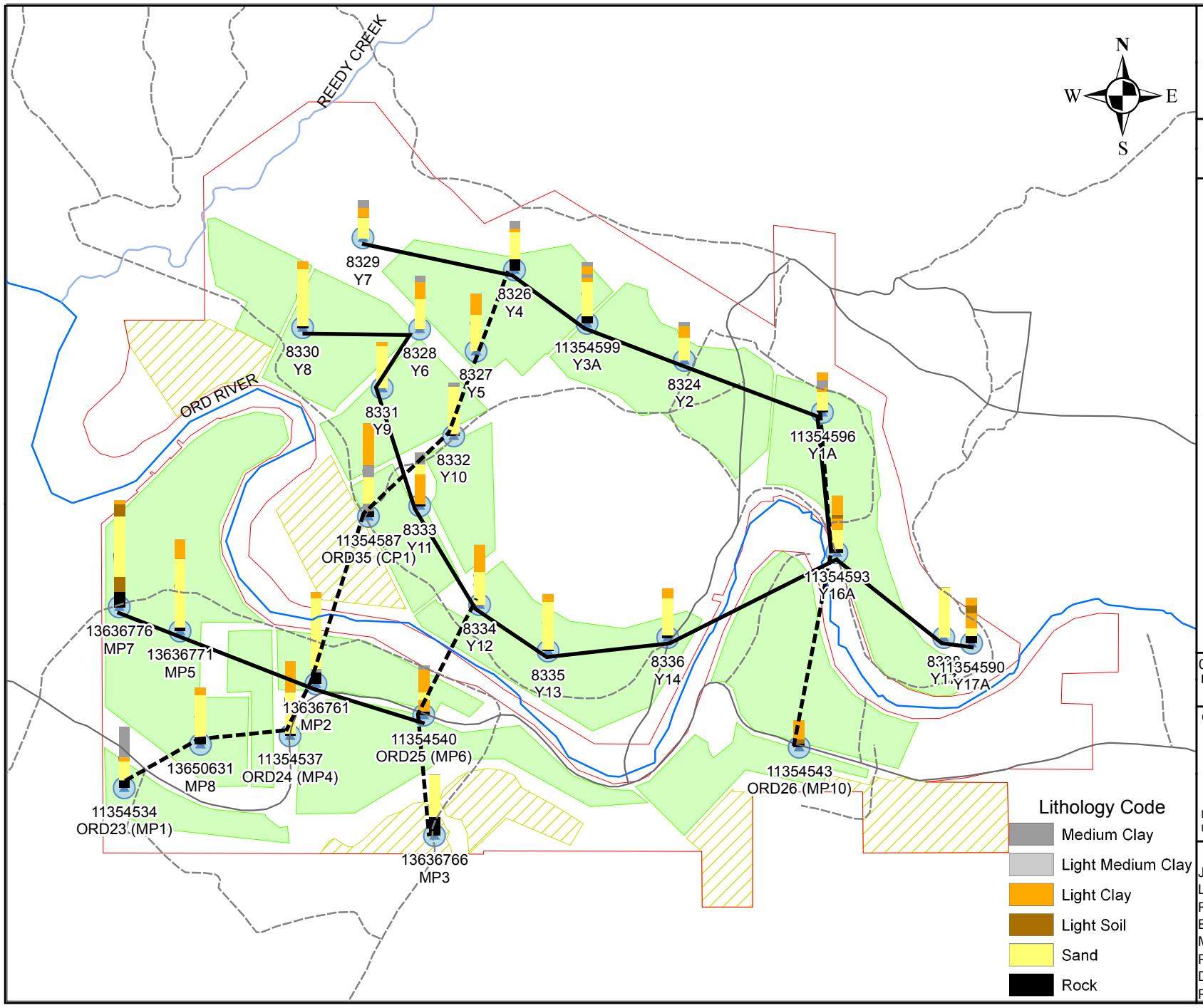
Map 1

The data available indicates that the troughs in these hydrographs are consistent in most sites that are within 4 to 5 km of the Ord River. In contrast, the water level has tended to rise with rainfall residual mass in the 6 piezometers north of House Roof Hill on Carlton Plain (Y1A, Y2, Y3A, Y4, Y6 and Y7) and in 2 piezometers near the southern boundary of Mantinea (MP1 and MP3). This indicates that deep drainage on these sites is close to the capacity of the underlying aquifer to transmit groundwater away from the piezometers. In contrast, the aquifer beneath the sites where the hydrographs fall to constant levels appears to have the capacity to convey the deep drainage at pre-development rates to a destination such as the Ord River. The capacity of this path to convey groundwater can be quantified by measurements such as pump tests.

The cross sections of groundwater levels (Map 2) indicate that there is generally greater variation in the water level at each site than there is across the site. In the transect north of House Roof Hill, the water level is generally 1 m higher at piezometer 11354956 (Y1A) than at piezometer 8329 (Y7), which is 11.5 km to the south west (Figure 5a). The greater depth to groundwater toward the eastern end of this transect appears to be correlated more closely with differences in surface elevation than to differences in the altitude of the groundwater surface.

The groundwater levels in the transect south of House Roof Hill (Figure 5b) can be subdivided into 3 groups. Groundwater levels in the 3 piezometers to the left of the river are generally deeper than 10 m. For the next 3 piezometers, there is a trend that groundwater generally falls from upstream (left) to downstream (8334 (Y12), on right). However the fall in surface level is steeper, so the water table becomes shallower with distance downstream. The shallowest groundwater levels in the last 3 piezometers are in piezometer 8326 (Y6), which is in a swamp indicated by the locally low surface level. The slope of the groundwater surface from 8328 (Y6) to 8330 (Y8) indicate that there is potential for some groundwater flow along this gradient and towards the Ord River, which is 1.3 km from 8330 (Y8, Map 2).

The transect through Mantinea shows a consistent fall of 2 m in the 7.5 km distance of the transect (Figure 5a). However, there is little fall in groundwater level from east to west.



Carlton Plain and Mantinea

Kununurra

Hydrograph
Cross Section Locations

HydrographTransects
- EastWest
- NorthSouth

Roads

CLASS
- Principal Road
- Secondary Road
- Minor Road
- Track

Watercourses
- Major
- Minor
- Piezometers
- Property Boundary

FarmArea

Area_Code
- Proposed Irrigation
- TimberArea

0 2.5 5
Kilometres

Certification

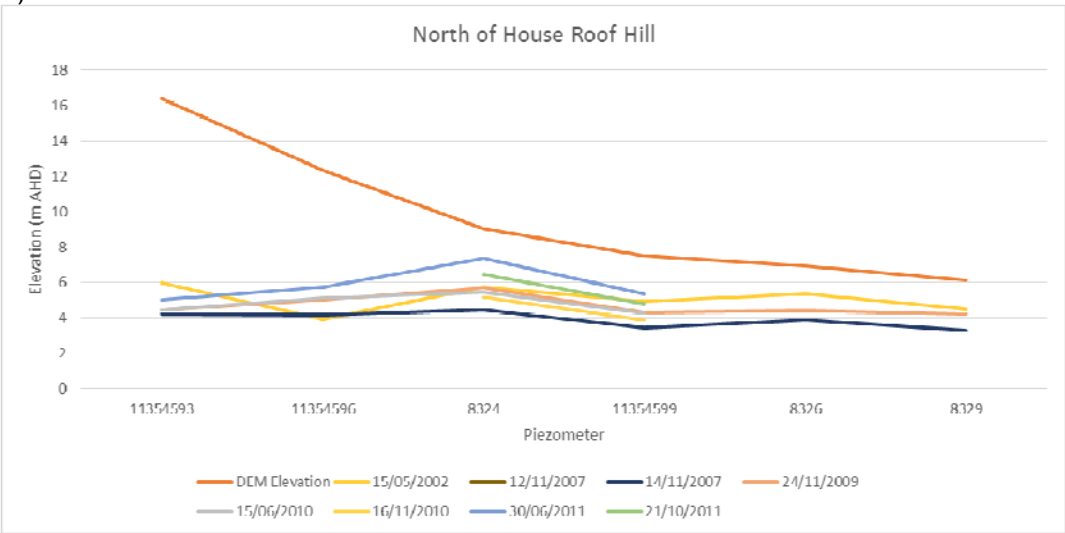
Draft/Uncontrolled Document
Unless Signed & Dated

Job Code: GW026
Lithology: WIN database
Roads, Watercourses: Geoscience Australia
Boundaries: KAI
Map Printed: 2017
Phone : (02) 68 473367
Datum: WGS 84
Projection: UTM

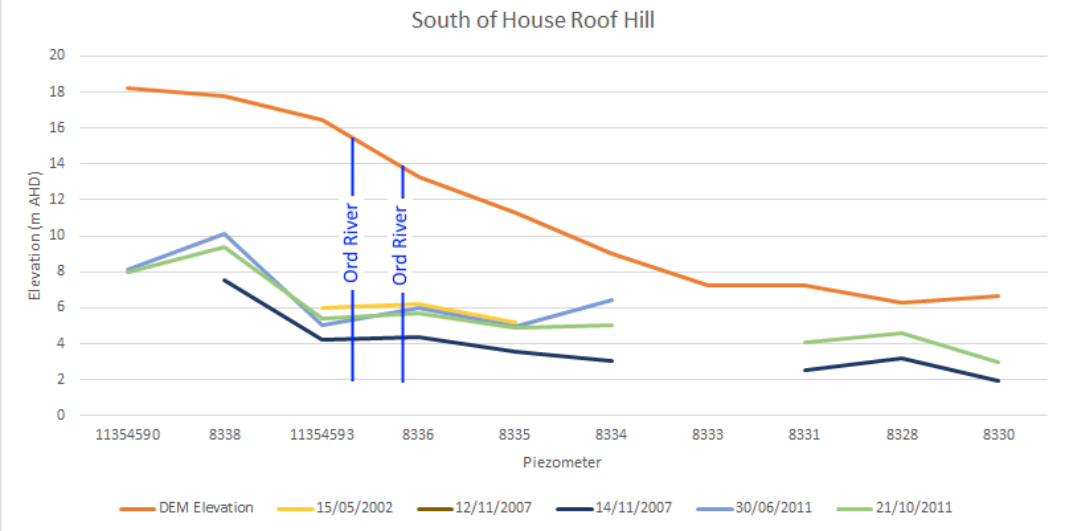
SSM Sustainable Soil Management

Map 2

a)



b)



c)

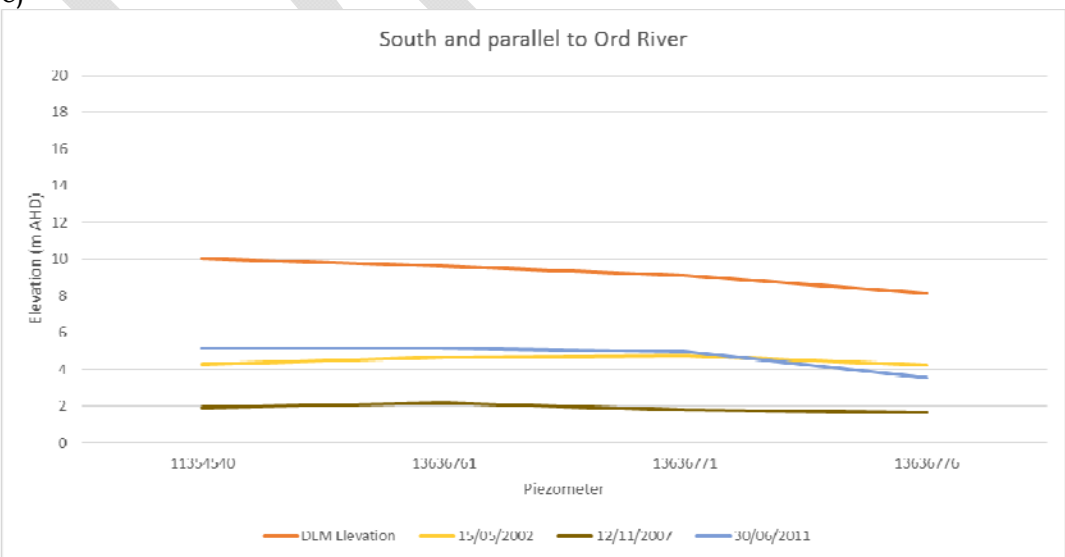
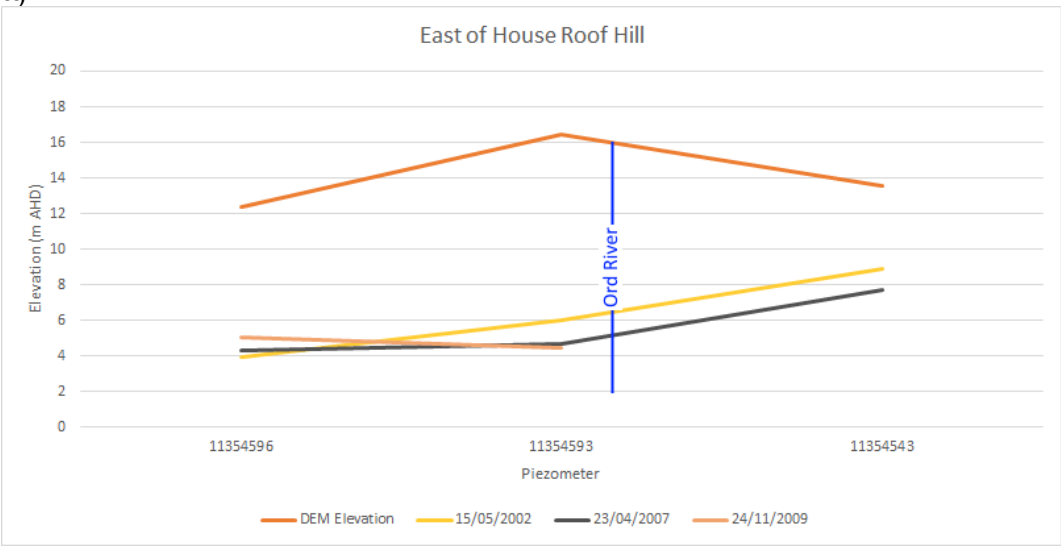


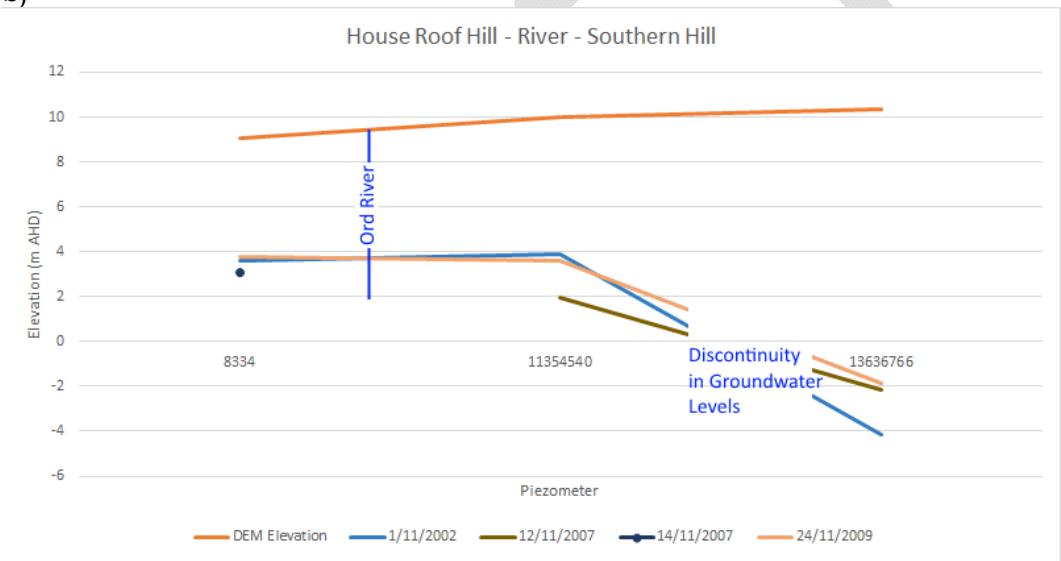
Figure 5. East-west transects of groundwater levels across Mantinea and Carlton Plain reduced to height above sea level (horizontal distances not to scale).

For the north-south transect east of House Roof Hill, piezometer 113545493 (Y1A), which is on the levee of the Ord River is the highest site, and has a groundwater level higher than 11354596 (Y1A) during wet, (Figure 6a) but not dry conditions (Figure 5a). In contrast, there is a fall of more than 2 m in the groundwater level from piezometer 113545493 (Y16A). Additional piezometers on Mantinea would be required to check whether groundwater can flow along this gradient. Both the ground surface and groundwater surface were level from piezometer 8334 (Y12) to 11354540 (MP6, Figure 6b). The water level in 13636766 (MP3) was lower than sea level. This indicates that there is little threat of leakage through this rock raising groundwater levels. The westernmost transect (Figure 6c) indicates a small fall in groundwater levels from the north of Carlton Plain (8326, Y4) to the Ord River. There is then little trend in groundwater levels across Mantinea except that water levels are slightly higher in 11354534 (MP1). This brings the water level close to the surface at this point. Again, the highest section of the transect is the levee close to the Ord River.

a)



b)



c)

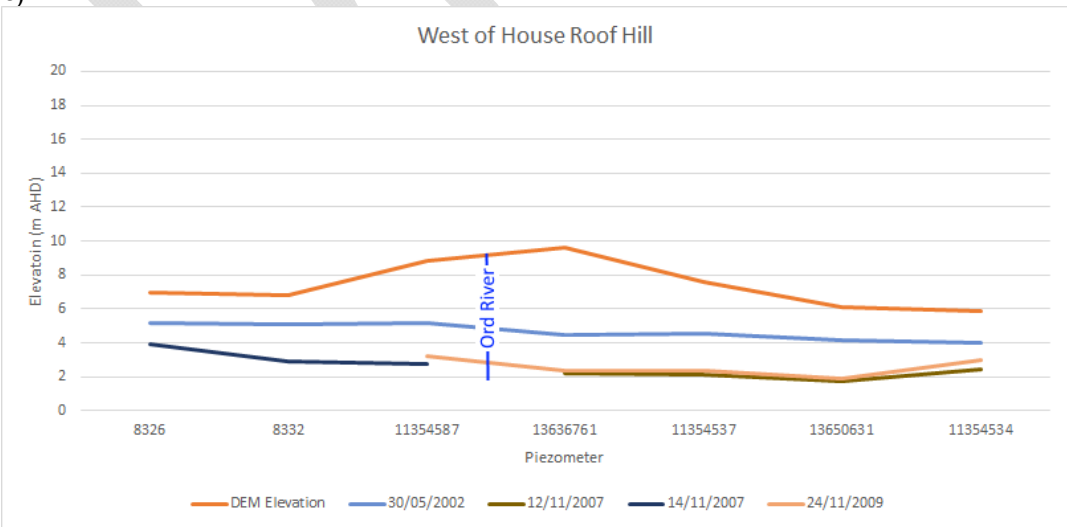


Figure 6. North-south transects of groundwater levels across Mantinea and Carlton Plain reduced to height above sea level (horizontal distances not to scale).

These transects show there is a small fall in groundwater levels parallel to the Ord River, that there is trend for groundwater levels to become higher with distance from the river. The zone north of House Roof Hill appears to have little groundwater outflow.

This small trend in groundwater elevation means that the elevation of the surface has a large effect on the depth to groundwater.

Seasonal patterns of recharge and discharge also have a large effect on groundwater levels.

Assessment of Risk of Irrigation Induced Salinity based on Test Hole and Piezometer Data

Shallow groundwater has been demonstrated to be the key cause of irrigation induced salinity because there is greater deep drainage under irrigated land than beneath the grassland or woodland that it replaces. One simple way of estimating the rate of water table rise is to apply constant deep drainage beneath the irrigated land and assume that there is no increase in groundwater outflow (Figure 2), which is likely or discharge into the Ord River. It is likely that the discharge from land near the river can increase but the magnitude is uncertain. Smith *et al.,* (2003) estimated that average deep drainage from fields and channels in the Ord River Irrigation Area was 26 mm/year from 1963 o 1990, but increased to 51 mm/year from 1990 to 2003 due to an increase in the area of sugar cane. Gunawardena *et al.,* (2011) measured average deep drainage of 22 mm/year from 3 positions in 9 fields over 2 to 7 cropping seasons. A moderately low deep drainage of 20 mm/year was adopted for this exercise on the basis that channels will be lined and a high standard of irrigation management applied.

The ratio of deep drainage to water table rise is the storage coefficient. Smith *et al.,* (2003) used a value of 10%, so this value was adopted for the current model.

The large fluctuations in water table depth caused by prolonged wet weather followed by years of drier weather mean that the average water table selected for a simple model is not straightforward. A depth of 3 m was selected for this model since this implies that the water table will be shallower than 2 m for part of the time.

These assumptions were applied to the data from piezometers across Mantinea and Carlton Plain. The result was that the water table was predicted to rise to within 3 m of the surface within 10 years in half of the piezometers (Table 1). The majority of these sites were west of the centre of House Roof Hill (Map 3). The exception was part of the western half of Mantinea. All the land upstream of the centre of House Roof Hill was predicted to take longer than 10 years for the average water table depth to rise to 3 m.

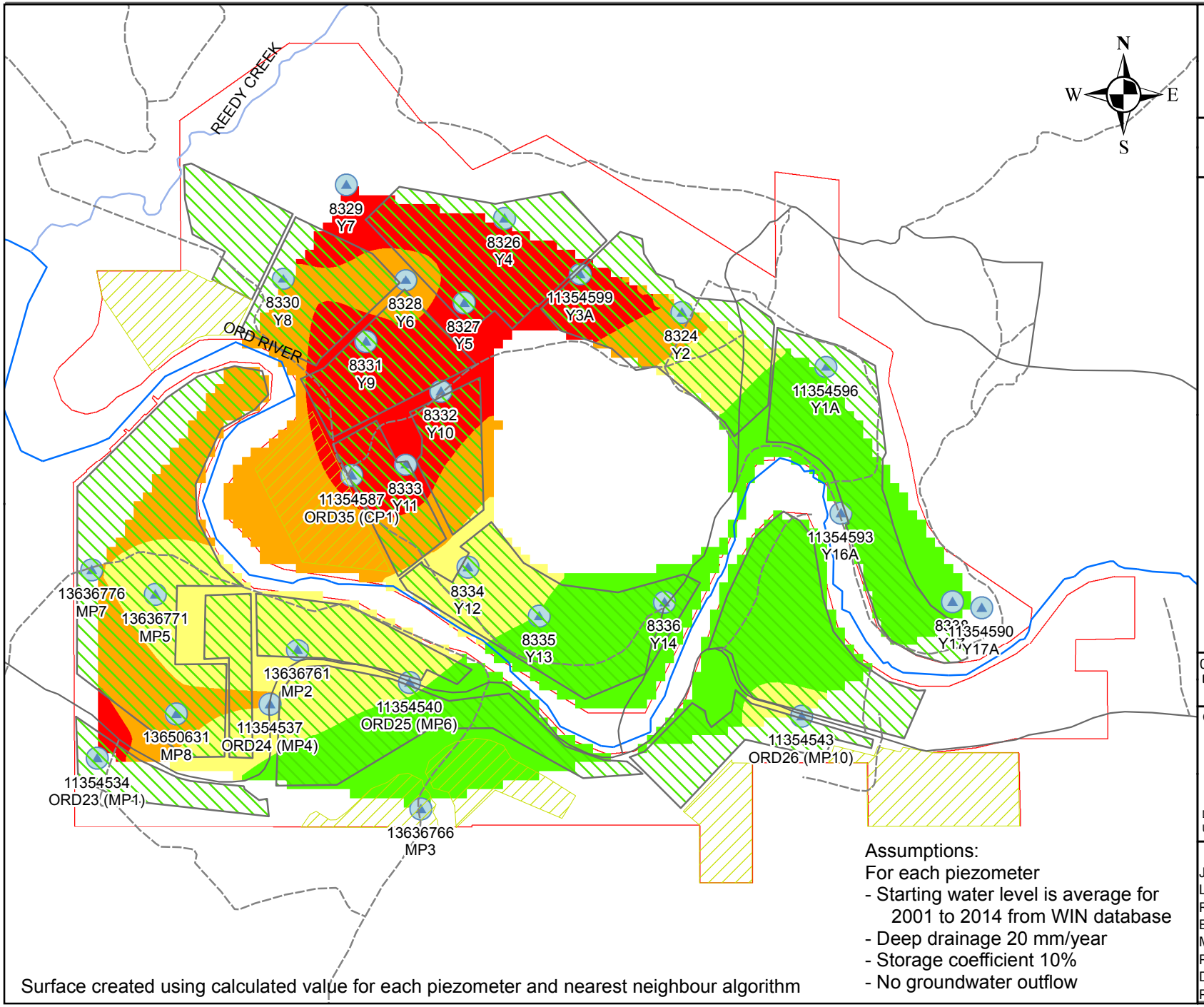
Table 1. Average water table depth for 2000 to 2014 for piezometers on Carlton Plain and Mantinea, estimated time for this average to increase to 3 m assuming deep drainage of 20 mm/year, average groundwater salinity, and proportion of blend with salinity of 600 mg/L that could be made of this water and Ord River water (assuming TDS of 180 mg/L).

Piezometer ID	Piezometer Name	Average SWL 2000 to 2014	Years to 3 m @ 20 mm deep drainage/year	Groundwater salinity (mg/L)	Groundwater as proportion of blend to get 600 mg/L
Carlton Plains					
8326	Y 4	2.1	0	9600	4%
8329	Y 7	2.1	0	16000	3%
8333	Y11	2.2	0	4900	9%
11354599	Y 3	2.9	0	15200	3%
8332	Y10	3.3	<5	4900	9%
8331	Y 9	3.6	<5	20200	2%
8330	Y 8	4.2	5 to 10	4000	11%
8324	Y 2	4.2	5 to 10	9600	4%
8328	Y 6	4.6	5 to 10	31200	1%
8334	Y12	5.7	10 to 20	6200	7%
8335	Y13	7	10 to 20	6200	7%
11364596	Y 1	8	20 to 40		
8336	Y14	8.8	20 to 40	6200	7%
11354590	Y17A	10.5	20 to 40		
8338	Y17	11	20 to 40	400	100%
11354593	Y16	12.3	>40		
Mantinea					
11354534	MP 1	3.3	<5	32000	1%
11354537	MP 4	4.8	5 to 10	10000	4%
13650631	MP 8	4.8	5 to 10	16000	3%
13636776	MP 7	4.9	5 to 10	25000	2%
13636771	MP 5	5.6	10 to 20	12000	4%
13636761	MP 2	5.7	10 to 20	4000	11%
11354543	MP10	6.1	10 to 20	2000	23%
11354540	MP 6	6.4	10 to 20	16000	3%
11354540	MP 6	6.4	10 to 20	16000	3%
13636766	MP 3	11.9	>40	1000	51%

Carlton Plain and Mantinea

Kununurra

Modelled time for water table to rise to 3 m



Surface created using calculated value for each piezometer and nearest neighbour algorithm

Assumptions:
For each piezometer
- Starting water level is average for 2001 to 2014 from WIN database
- Deep drainage 20 mm/year
- Storage coefficient 10%
- No groundwater outflow

Years to 3 m SWL at 20 mm/year

- Less than 5
- 5 to 10
- 10 to 20
- More than 20

FarmArea

Area_Code

- Proposed Irrigation
- TimberArea
- Piezometers
- Property Boundary

Roads

CLASS

- Principal Road
- Secondary Road
- Minor Road
- Track

Watercourses

- Major
- Minor

0 2.5 5
Kilometres

Certification

Draft/Uncontrolled Document
Unless Signed & Dated

Job Code: GW026
Lithology: WIN database
Roads, Watercourses: Geoscience Australia
Boundaries: KAI
Map Printed: 2017
Phone : (02) 68 473367
Datum: WGS 84
Projection: UTM

SSM Sustainable Soil Management

Map 3

One way of lowering the water table is to remove water using pumping or drains. The water could be used for irrigation if it is not disposed of. Ali *et al.,* (2003) used a critical water salinity of 600 mg/L and Ord River water salinity of 180 mg/L when assessing the suitability of groundwater for irrigation. These critical values were applied to the average groundwater salinity to estimate the proportion of a blend that could be made up of groundwater while maintain the critical salinity. The calculation estimates that groundwater from sites with historic water table depth shallower than 5 m could make up an average of 4% of a blend, while those where historic water table depth was greater than 8 m could make up an average of 50% of a blend of irrigation water that could be used for a wide range of crops (Table 1).

Airborne Electromagnetic Findings Summary

The Ord Valley Airborne Electromagnetic (AEM) project mapped the properties of the alluvium across Mantinea and Carlton Plain at a finer resolution than obtained from the test holes described above. However, this project described conditions only at the time of the assessment. Some key properties relevant to irrigation salinity are described in this section.

The geomorphology aims to group areas where the material that transmits water has been formed by similar processes, so would be expected to have similar properties. The majority of the area of proposed irrigation on Carlton Plain is mapped as Alluvial Plain (Map 4a) which is described by Lawrie *et al.,* (2010) as a level land surface produced by extensive deposition of alluvium. There are several areas on Carlton Plain west of House Roof Hill that are mapped as Swamps because they are closed depressions. These are likely to have a seasonal water table at or above the surface (Lawrie *et al.,* 2010). The remainder of proposed irrigation on Carlton Plain is mapped as Levee, which is a long, narrow, sinuous ridge that has been built from overbank flow from an adjacent river. The parts of Carlton Plain inside meanders of the Ord River were mapped as Meander Plain, which contain a number of moderately deep alluvial stream channels.

The units of Alluvial Plain, Levee and Meander Plain also occur on Mantinea, however, there is a much smaller proportion of Alluvial Plain (Map 4a). In addition, there are several strips mapped as Oxbows near the southwestern corner. These are closed depressions that often hold water (Lawrie *et al.,* 2010).

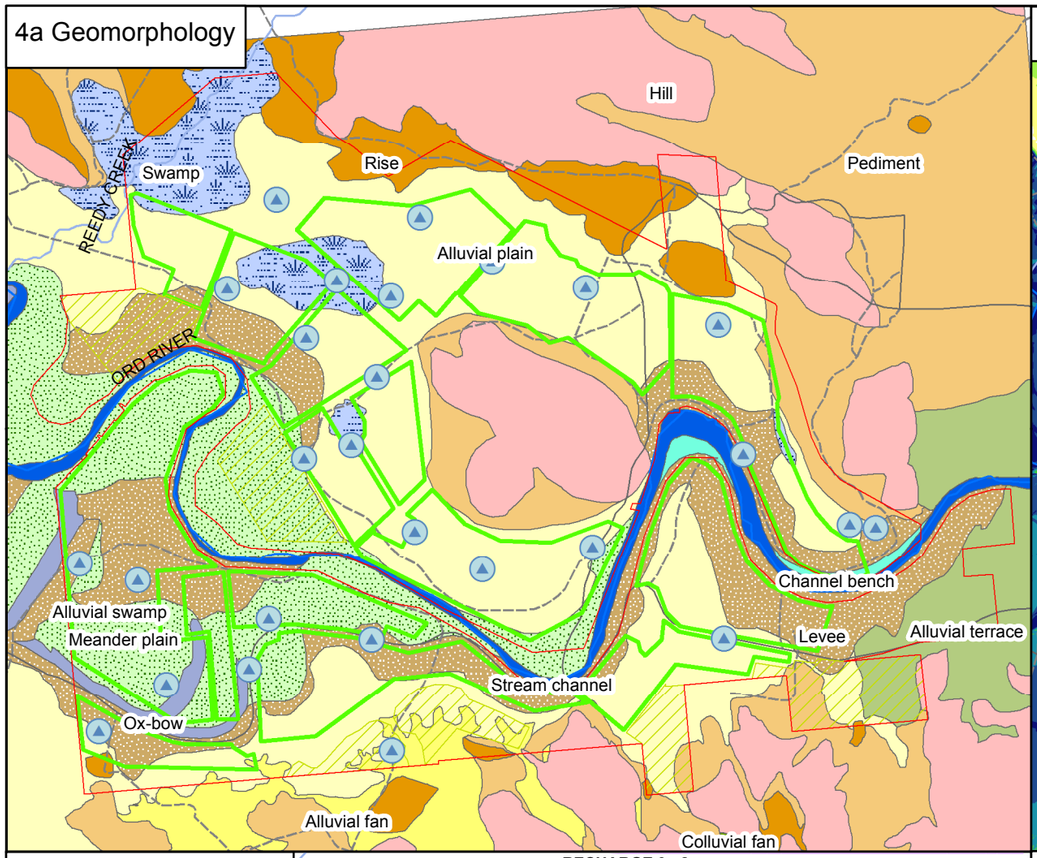
The depth to groundwater generally decreases from upstream to downstream (Map 4b). The trend appears reasonably uniform on Carlton Plain however, the finer resolution of the Digital Elevation Model on Mantinea show that the water table is very shallow in the Oxbows near the southwestern comer.

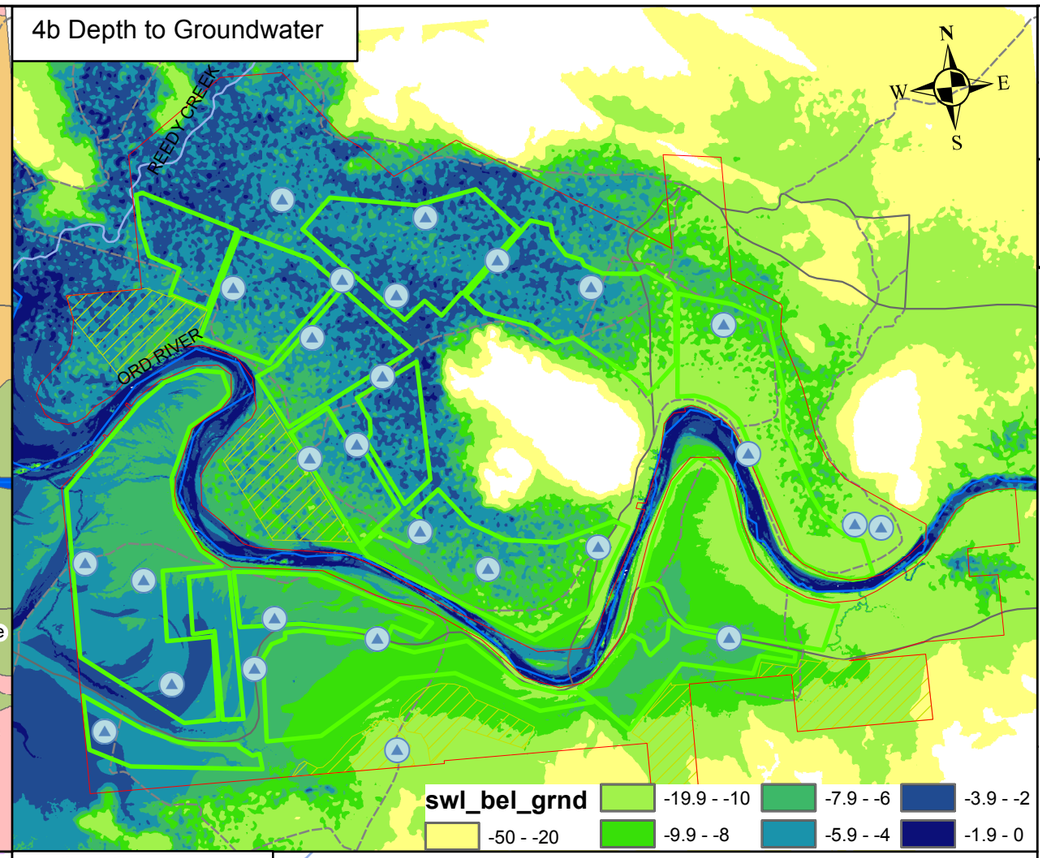
The potential recharge surface shows that the majority of the area mapped as Alluvial Plain in Map 4a has Slow or Very Slow potential recharge rate (Map 4c). The areas mapped as Levee are generally attributed a moderate recharge rate, while the Meander Plain has moderate to rapid potential recharge rate.

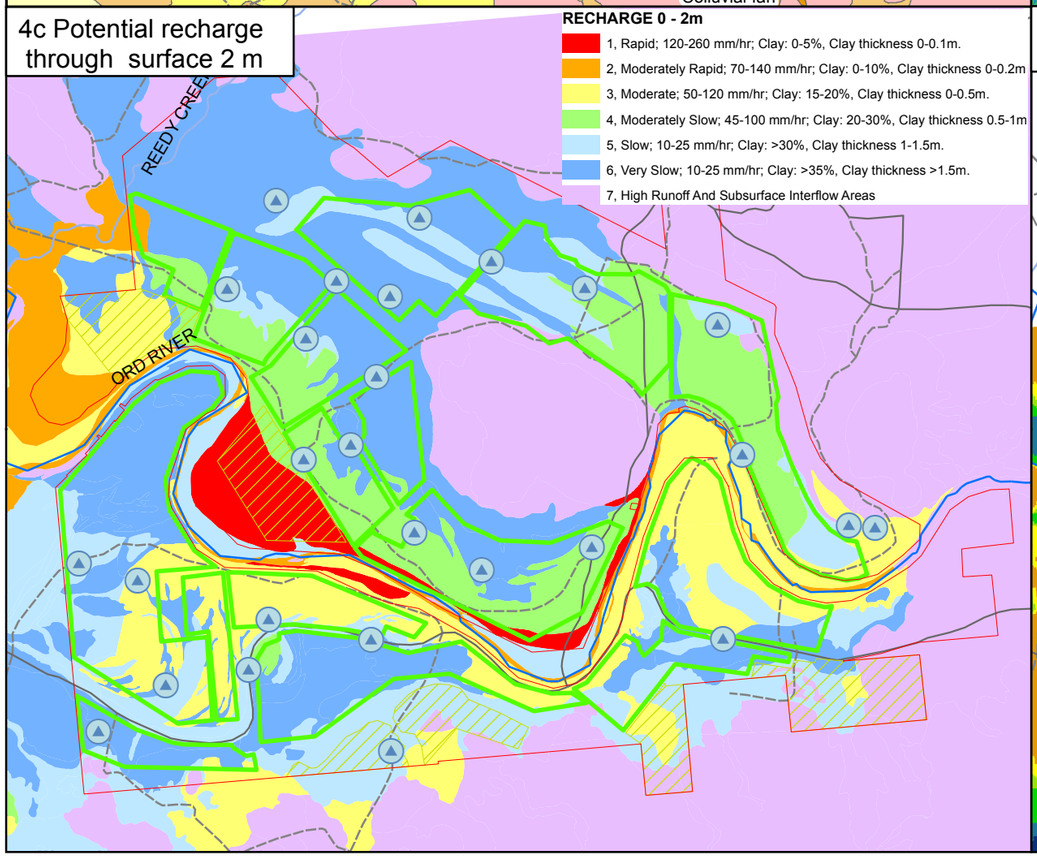
Mantinea and Carlton Plain

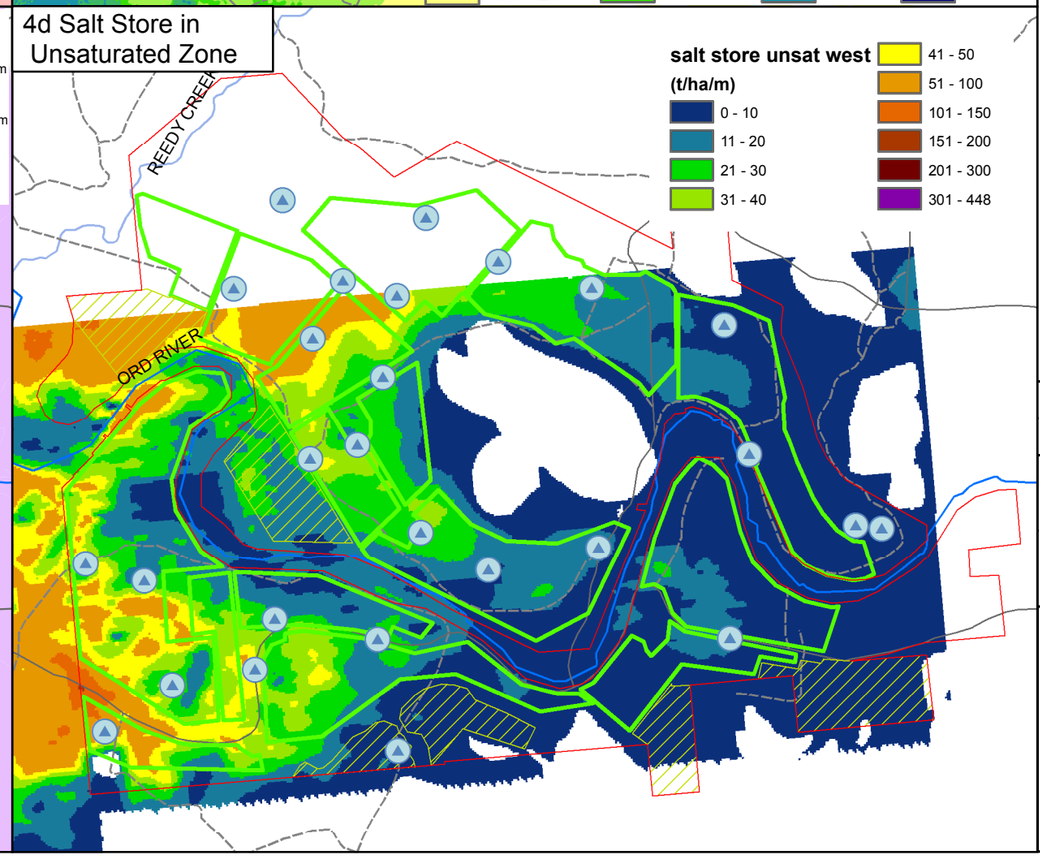
Kununurra

Salinity Precursors from Ord Valley Airborne EM Project (Geoscience Australia)









Piezometers

Property Boundary

FarmArea

Area_Code

Field

TimberArea

Roads

CLASS

Principal Road

Secondary Road

Minor Road

Track

Watercourses

HIERARCHY

Major

Minor

0 2,000 4,000 6,000 8,000

Metres

Certification

Draft/Uncontrolled Document
Unless Signed & Dated

Job Code: GW026
Boundaries: KAI
Roads, Watercourses: Geosci
Map Printed: 2017
Contact: Sustainable Soils Management
Phone : (02) 68 473367

SSM Sustainable Soil Management

Datum: WGS 84
Projection: UTM

Map 4

The salt store in above the water table generally increases rapidly from the upstream end of Carlton Plain and Mantinea to the downstream (Map 4d). This occurs despite a trend of the unsaturated zone becoming thinner from upstream to downstream. The largest salt store occurs in the area of Carlton Plain west of House Roof Hill and near the western edge of Mantinea.

Lawrie *et a*l., (2010) estimated salinity hazard from a combination of depth to water table and unsaturated zone salt store. Essentially, the greatest hazard occurs with a combination of shallow water table and large salt store (Figure 7). Conversely, the salinity hazard is rated as low in areas with deep water table and small salt store.

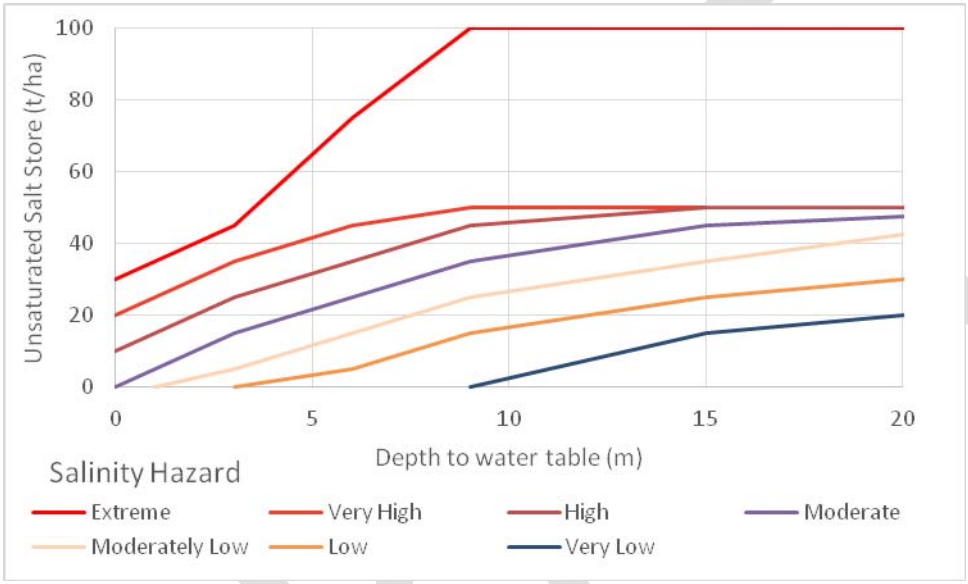
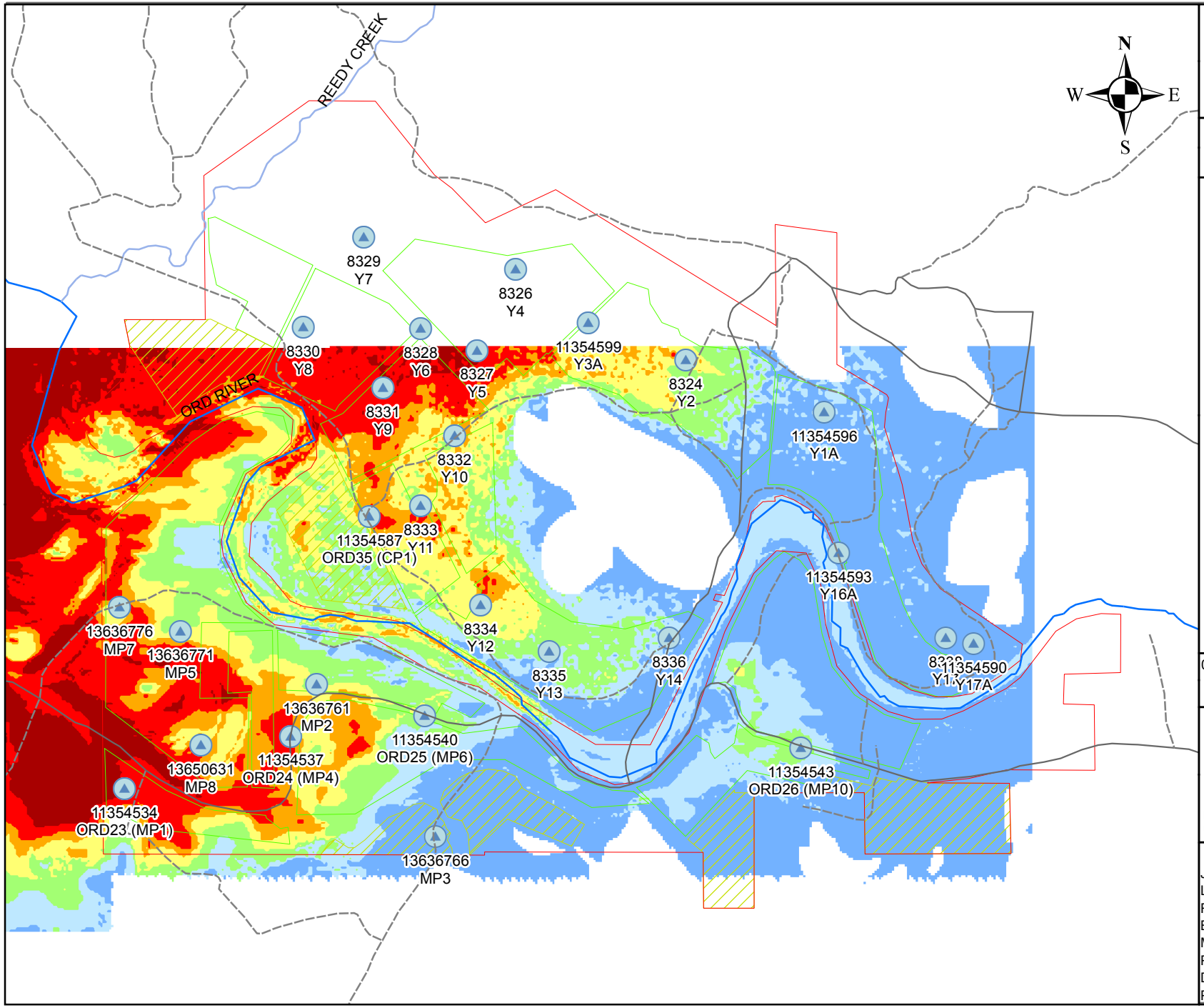


Figure 7. Critical values used by Lawrie et al., (2010) to estimate salinity hazard.

The resulting map (Map 5) shows a similar pattern to the estimated time for the water table to reach 3 m (Map 3) in that salinity hazard generally increased from Very Low upstream of House Roof Hill to Very High in Carlton Plain west of House Roof Hill, and Very High to Extreme for much of the westernmost 2 to 3 km in Mantinea.

The Salinity Hazrd map identifies a 1 to 2 km wide strip adjacent to the Ord River with Low to Moderately Low salinity hazard that was not identified by the piezometers and test holes alone.



Carlton Plain and Mantinea

Kununurra

Unsaturated Zone Salinity Hazard (Geoscience Australia)

Salt store hazard

- 1.Very Low
- 2. Low
- 3. Moderately Low
- 4. Moderate
- 5. High
- 6. Very High
- 7. Extremely High

Roads

CLASS

- Principal Road
- Secondary Road
- Minor Road
- Track

Watercourses

- Major
- Minor

- Piezometers
- Property Boundary

FarmArea

Area_Code

- Proposed Irrigation
- TimberArea

0 2.5 5

Kilometres

Certification

Draft/Uncontrolled Document
Unless Signed & Dated

Job Code: GW026
Lithology: WIN database
Roads, Watercourses: Geoscience Australia
Boundaries: KAI
Map Printed: 2017
Phone : (02) 68 473367
Datum: WGS 84
Projection: UTM

SSM Sustainable Soil Management

Map 5

Conclusions

- The groundwater system beneath Mantinea and Carlton Plain consists of a valley of slowly permeable rock that has been infilled with as much as 24 m of unconsolidated sediment. Much of the sediment in the downstream half of Carlton Plain and Mantinea was deposited in the sea bed (marine), while the sediment in much of the upstream half and strips beside the Ord River has been deposited by the river (alluvial). The marine sediment is much more saline than the alluvial sediment.
- The Ord River Palaeochannel, which conveys much of the groundwater flows beneath the Ord River Irrigation Area traverses the Weaber Plain and is not beneath Mantinea and Carlton Plain. As a result, the sediment beneath Carlton Plain and Mantinea is likely to have a much smaller capacity to convey groundwater than the sediment beneath the Ord River Irrigation Area.
- Both analysis of trends in groundwater levels and the more detailed Ord Valley Airborne Electromagnetic (AEM) project conclude that there is a very large increase in the risk of irrigation induced salinity from the upstream end of Carlton Plain and Mantinea to the downstream end of the proposed irrigation development on these properties.
- Upstream of about the centre of House Roof Hill, the majority of the proposed development has a Very Low Salinity Hazard. A simple groundwater balance indicates that a shallow water table is unlikely to develop for decades under good water management.
- In contrast, most of the proposed development on Carlton Plain downstream from House Roof Hill is rated as having Very High salinity hazard, and likely to develop a shallow water table after less than a decade of irrigation. Groundwater salinity in this area is high enough that it is unlikely to be practical to use water extracted to lower the water table for irrigation except at a very low proportion of a water blend (<5%).
- The literature review indicates that it will be very difficult to avoid the development of a shallow water table in this area because there are likely to be periods when large deep drainage brings the water table close to the surface. This land should not be irrigated.
- On Mantinea, the pattern of areas with shallow water table and Very High to Extreme salinity hazard is more complex. The AEM based salinity hazard map shows strips of Moderate and High salinity hazard. Careful planning would be required to irrigate this landscape without causing salinity.
- The finer resolution of the AEM salinity hazard map identifies a broad strip of deeper water table and Low salinity hazard along the Ord River that was not sampled by the test holes used to generate the depth to water table map.

REFERENCES

Ali, R., and Salama, R.S., 2003. Groundwater quality in the Ord Irrigation Area, its suitability for irrigation and prediction of salinity and sodicity hazards. CSIRO Land and Water Technical Report 7/03.

Ali, R., Byrne, J., and Slaven, T., 2010. Modelling irrigation and salinity management strategies in the Ord Irrigation Area. Natural Resources. 1:34-56.

Ali, R., Salama, R.S., Pollock, D.W., and Bates, L, 2002. Geochemical interactions between groundwater and soil, groundwater recycling and evaporation in the ORIA. CSIRO Land and Water Technical Report 21/02.

Bhattarai, S.P. and Midmore, D.J., 2015. Advanced drip and optimised furrow irrigation to minimise sediment, nutrient and pesticide losses to the environment through deep drainage and run-off from sugarcane and banana industries in northern Queensland. Report to the Reef Rescue Water Quality Research & Development Program. Reef and Rainforest Research Centre Limited, Cairns (41pp.). ISBN: 978-1-925088-74-8.

Brouwer, C., Goffeau, A. and Heiblom, M., 1985. Irrigation Water Management Training Manual No. 1 - Introduction to Irrigation. Food and Agriculture Organisation, Rome.

Dalton, P., Raine, S., and Broadfoot, K., 2003. Best management practices for maximising whole farm irrigation efficiency in the Australian cotton industry. Final Report for CRDC Project NEC2C, National Centre for Engineering an Agriculture Publication 179707/2, USQ Toowoomba.

Department of Natural Resources., 1997. Salinity Management Handbook. Scientific Publishing, Resource Sciences Centre. 214 pp.

Gunawardena, T.A., McGarry, D., Robinson, J.B., and Silburn, D.M., 2011. Deep drainage through Vertosols in irrigated fields using drainage lysimeters. Soil Research. 49: 343-354.

Lawrie, K.C., Tan, K.P., Clarke, J.C., Munday, T.J., Fitzpatrick, A., Brodie, R.S., Apps, H., Halas, L., Cullen, K., Pain, C.F., Kuske, T.J., Cahill, K., and Davis, A., 2010. Using the SkyTEM Time Domains Airborne Electromagnetics (AEM) System to Map Aquifer Systems and Salinity Hazard in the Ord Valley, Western Australia. Geoscience Australia Professional Opinion 2010/01, 500 pp.

Smith, A.J., Pollock, D.W., and Palmer, D., 2006. Groundwater management options to control rising groundwater level in the Ord Stage 1 Irrigation Area, Western Australia CSIRO Land and Water Technical Report 70/06.

Smith, A.J., Pollock, D.W., Salama, R.S., and Palmer, D., 2005. Ivanhoe Plain aquifer pumping trial July 2003 - April 2005: Stage 1 Ord River Irrigation Area, Kununurra, Western Australia. CSIRO Land and Water Technical Report 24/05.

Smith, A.J., Salama, R.B., and Pollock, D.W., 2003. Groundwater flow modelling of Ivanhoe and Packsaddle Plains: Interim Report of model development and calibration. CSIRO Land and Water Technical Report 38/03.

LIMITATIONS

The investigations described in this report identified actual conditions only at those locations where sampling occurred. This data has been interpreted and an opinion given regarding the overall physical and chemical conditions at the site.

Although the information in this report has been used to interpret conditions at the site, actual conditions may vary from those inferred, especially between sampling locations. Consequently, this report should be read with the understanding that it is a professional interpretation of conditions at the site based on a set of data. Although the data were considered representative of the site they cannot fully define the conditions across the site.

APPENDIX I:

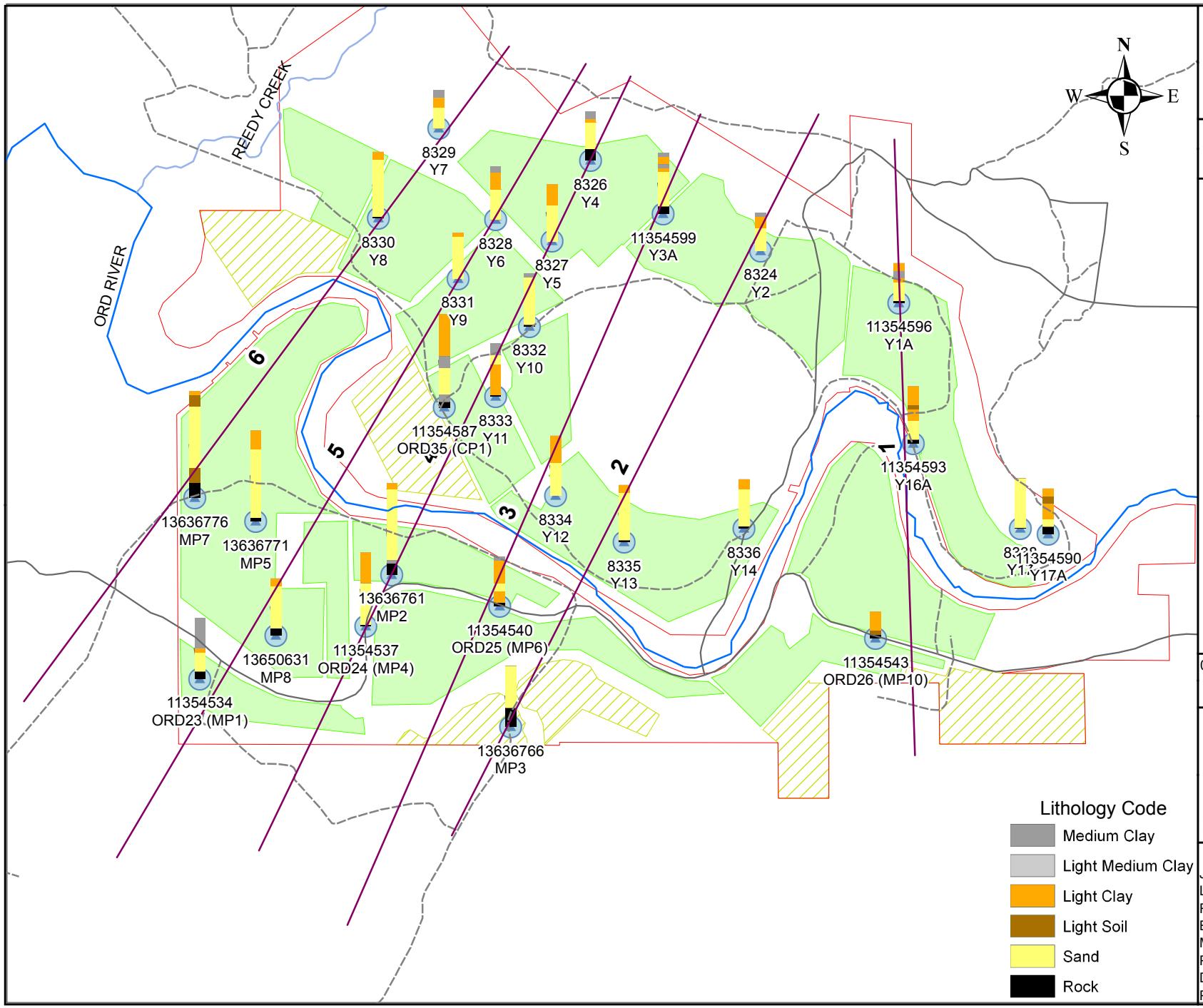
Hydrogeological Cross Sections beneath Mantinea and Carlton Plain:

from Ord Valley Airborne EM Project (Lawrie et al., 2010)

Carlton Plain and Mantinea

Kununurra

Hydrogeology Cross Section Locations



Hydrogeology Cross Section

Roads

CLASS

- Principal Road
- Secondary Road
- Minor Road
- Track

Watercourses

- Major
- Minor
- Piezometers
- Property Boundary

FarmArea

Area_Code

- Proposed Irrigation
- TimberArea

0 2.5 5
Kilometres

Certification

Draft/Uncontrolled Document
Unless Signed & Dated

Job Code: GW026
Lithology: WIN database
Roads, Watercourses: Geoscience Australia
Boundaries: KAI
Map Printed: 2017
Phone : (02) 68 473367
Datum: WGS 84
Projection: UTM

SSM Sustainable Soil Management

MapA1.1

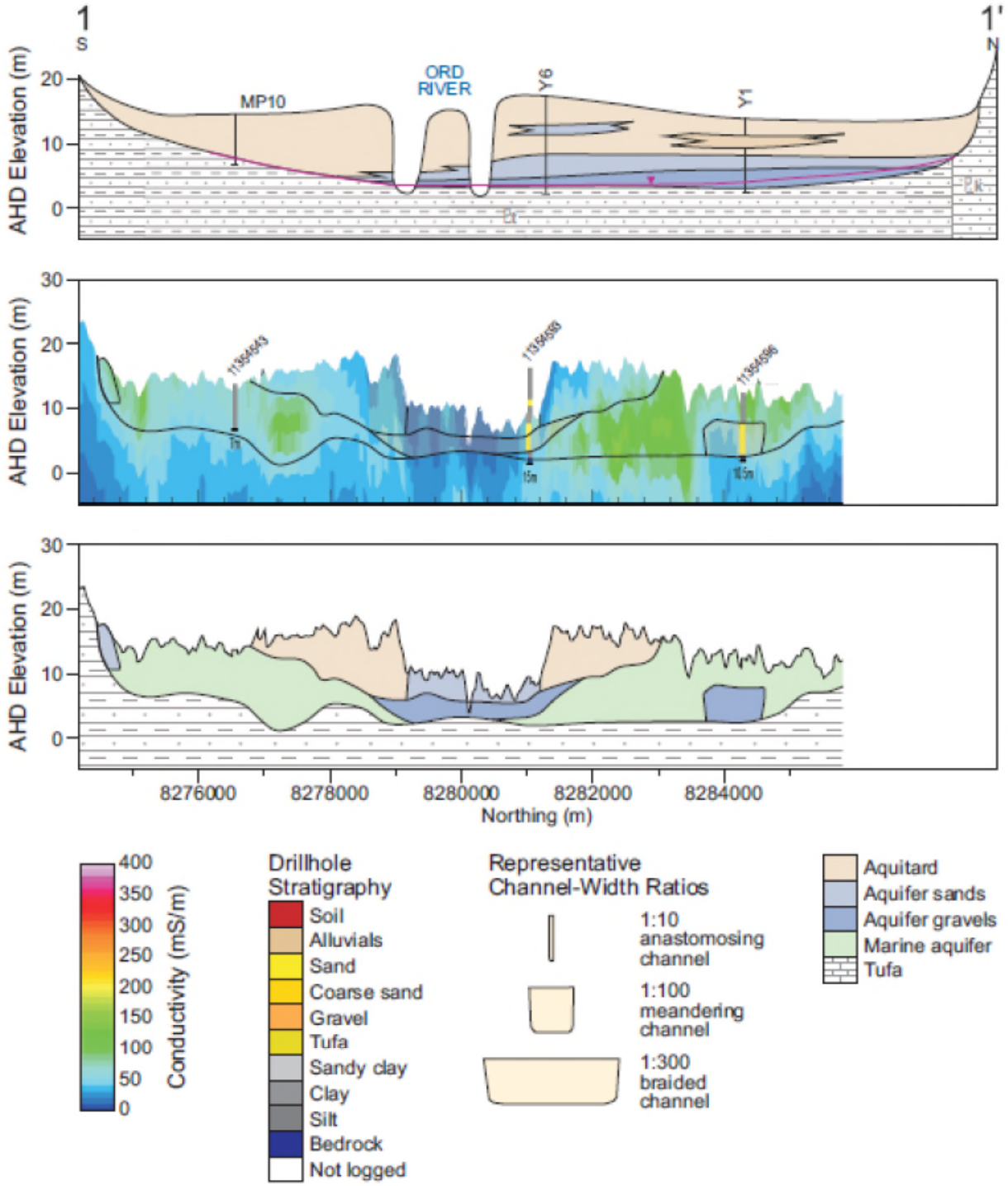


Figure 262: *Parry's Lagoon- Mantinea Plain- Carlton Hill cross section 1-1'. Top panel is cross-section from O'Boy et al., (2001); middle panel is synthetic AEM section showing drillholes colour coded for lithology and with lithology extent interpretation line work displayed; bottom panel is revised lithology interpretation produced in this study.*

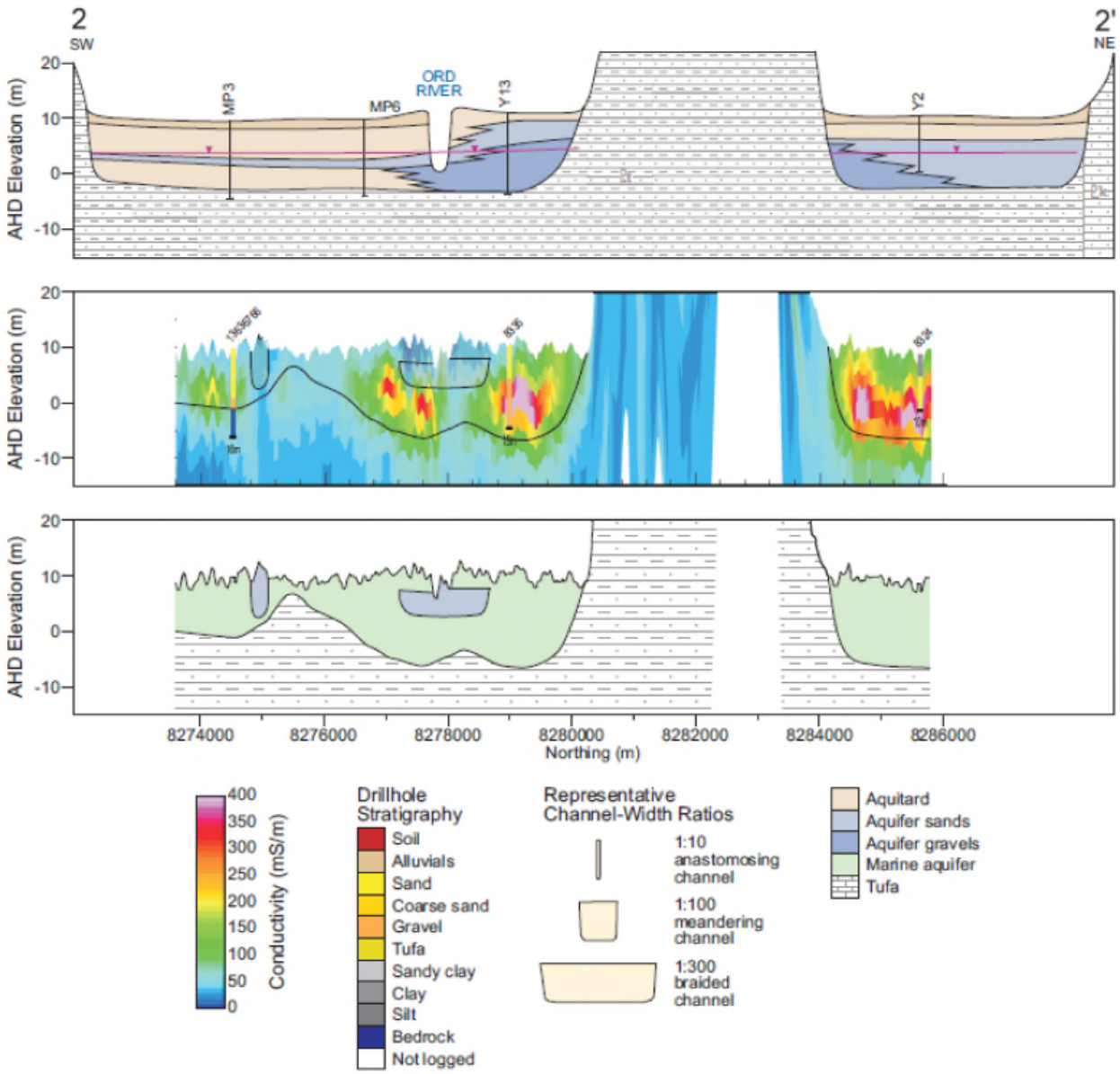


Figure 263: *Parry's Lagoon- Mantinea Plain- Carlton Hill cross section 2-2'. Top panel is cross-section from O'Boy et al., (2001); middle panel is synthetic AEM section showing drillholes colour coded for lithology and with lithology extent interpretation line work displayed; bottom panel is revised lithology interpretation produced in this study.*

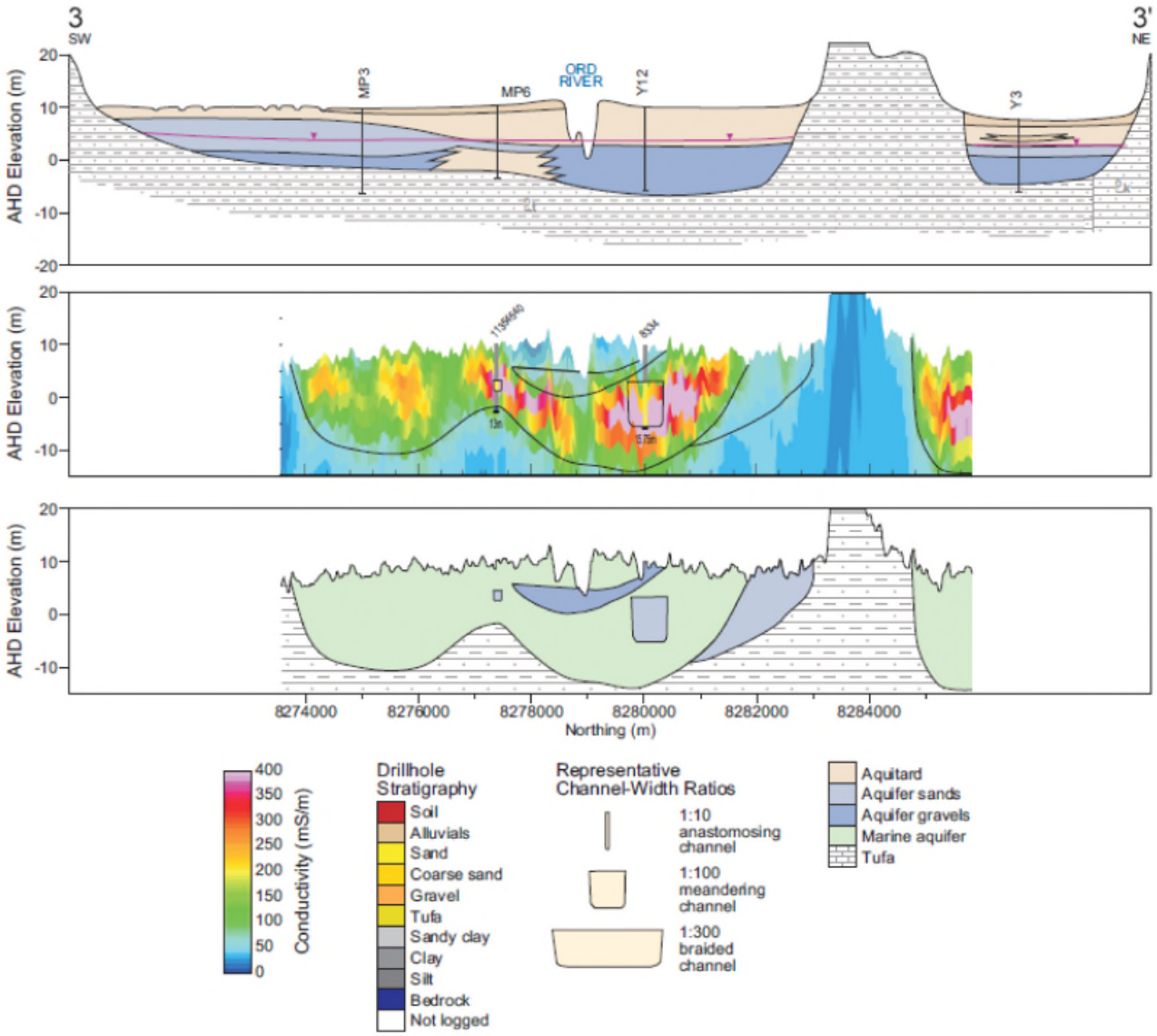


Figure 264: *Parry's Lagoon- Mantinea Plain- Carlton Hill cross section 3-3'. Top panel is cross-section from O'Boy et al., (2001); middle panel is synthetic AEM section showing drillholes colour coded for lithology and with lithology extent interpretation line work displayed; bottom panel is revised lithology interpretation produced in this study.*

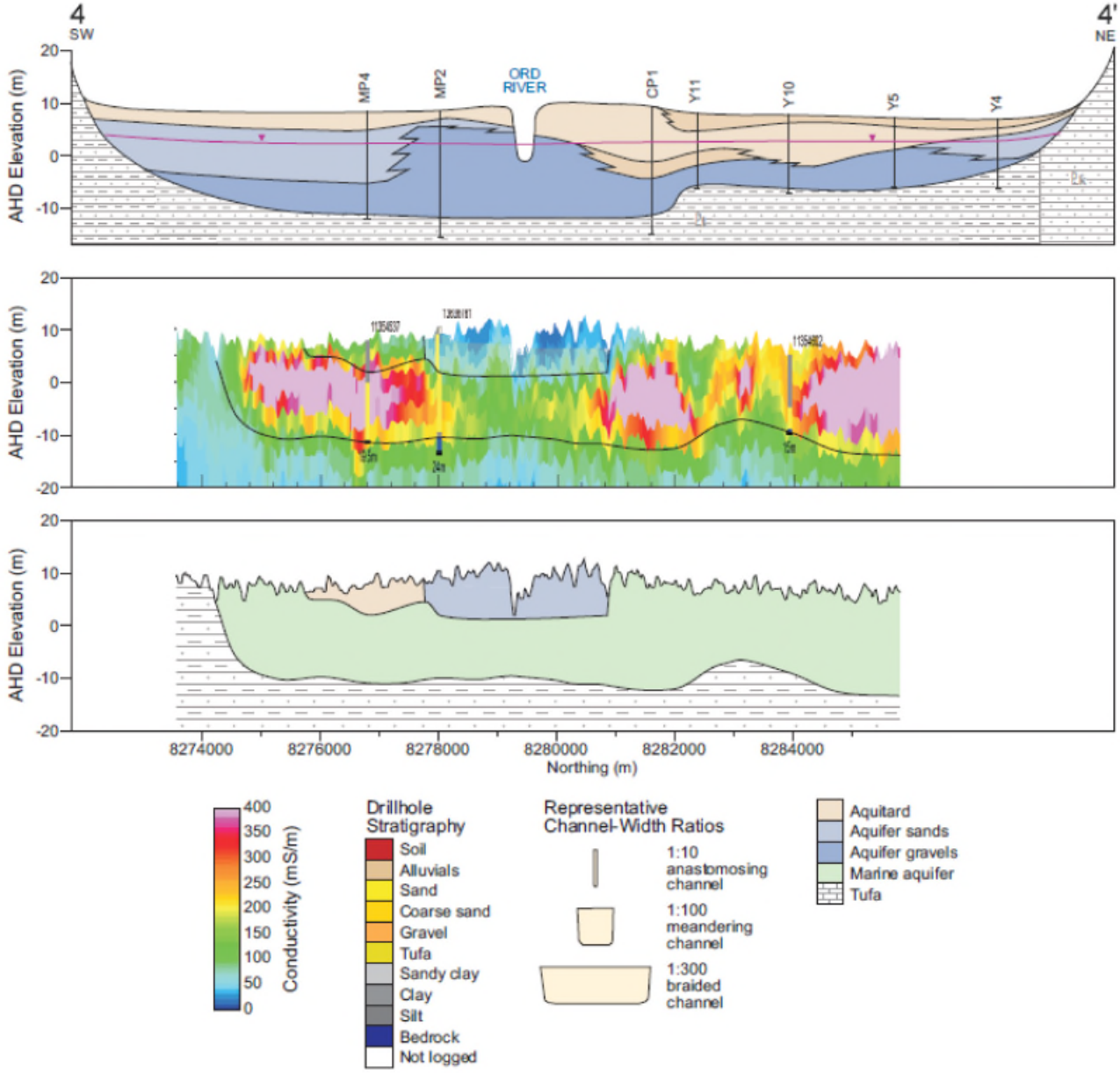


Figure 265: *Parry's Lagoon- Mantinea Plain- Carlton Hill cross section 4-4'. Top panel is cross-section from O'Boy et al., (2001); middle panel is synthetic AEM section showing drillholes colour coded for lithology and with lithology extent interpretation line work displayed; bottom panel is revised lithology interpretation produced in this study.*

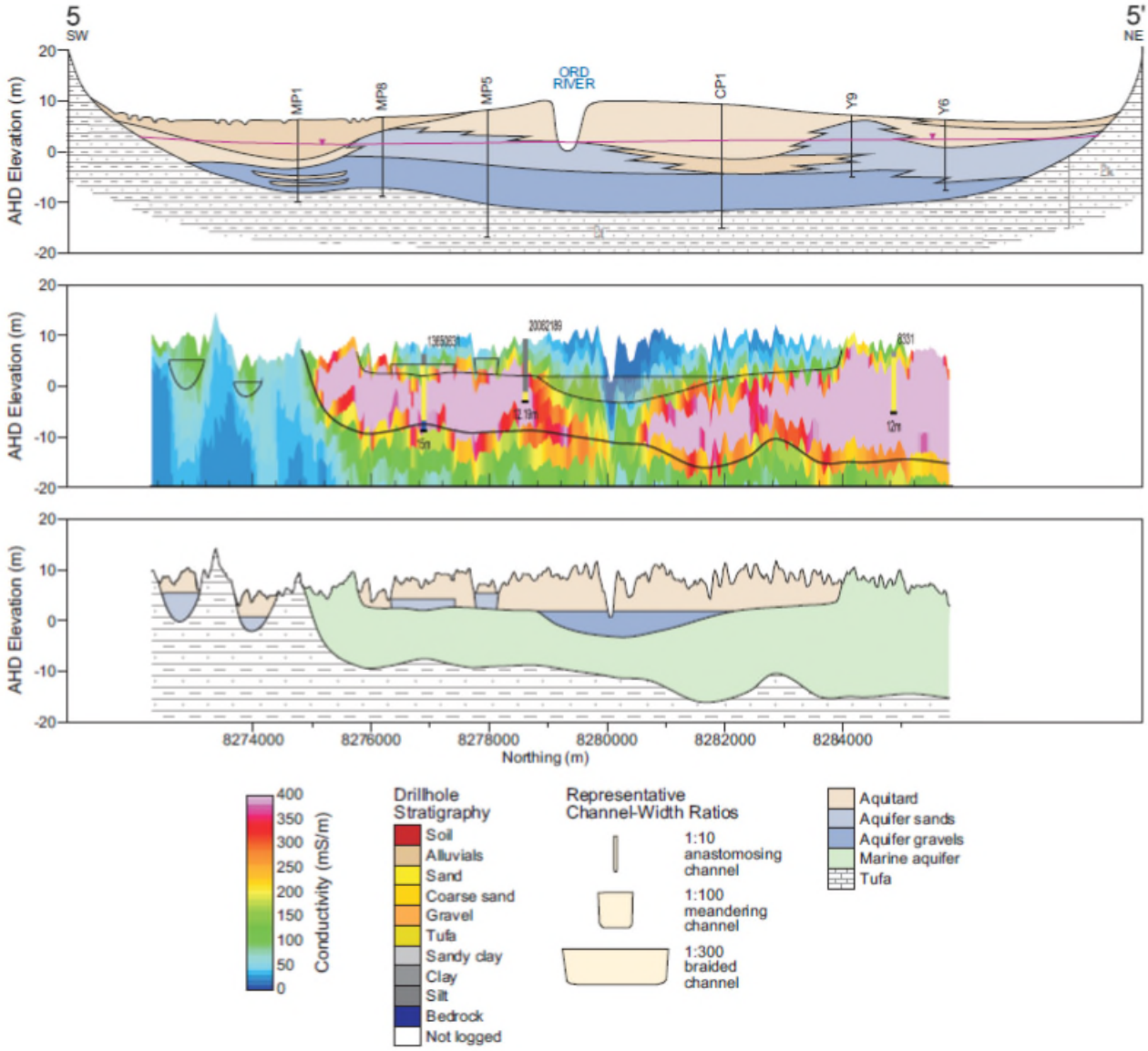


Figure 266: *Parry's Lagoon- Mantinea Plain- Carlton Hill cross section 5-5'. Top panel is cross-section from O'Boy et al., (2001); middle panel is synthetic AEM section showing drillholes colour coded for lithology and with lithology extent interpretation line work displayed; bottom panel is revised lithology interpretation produced in this study.*

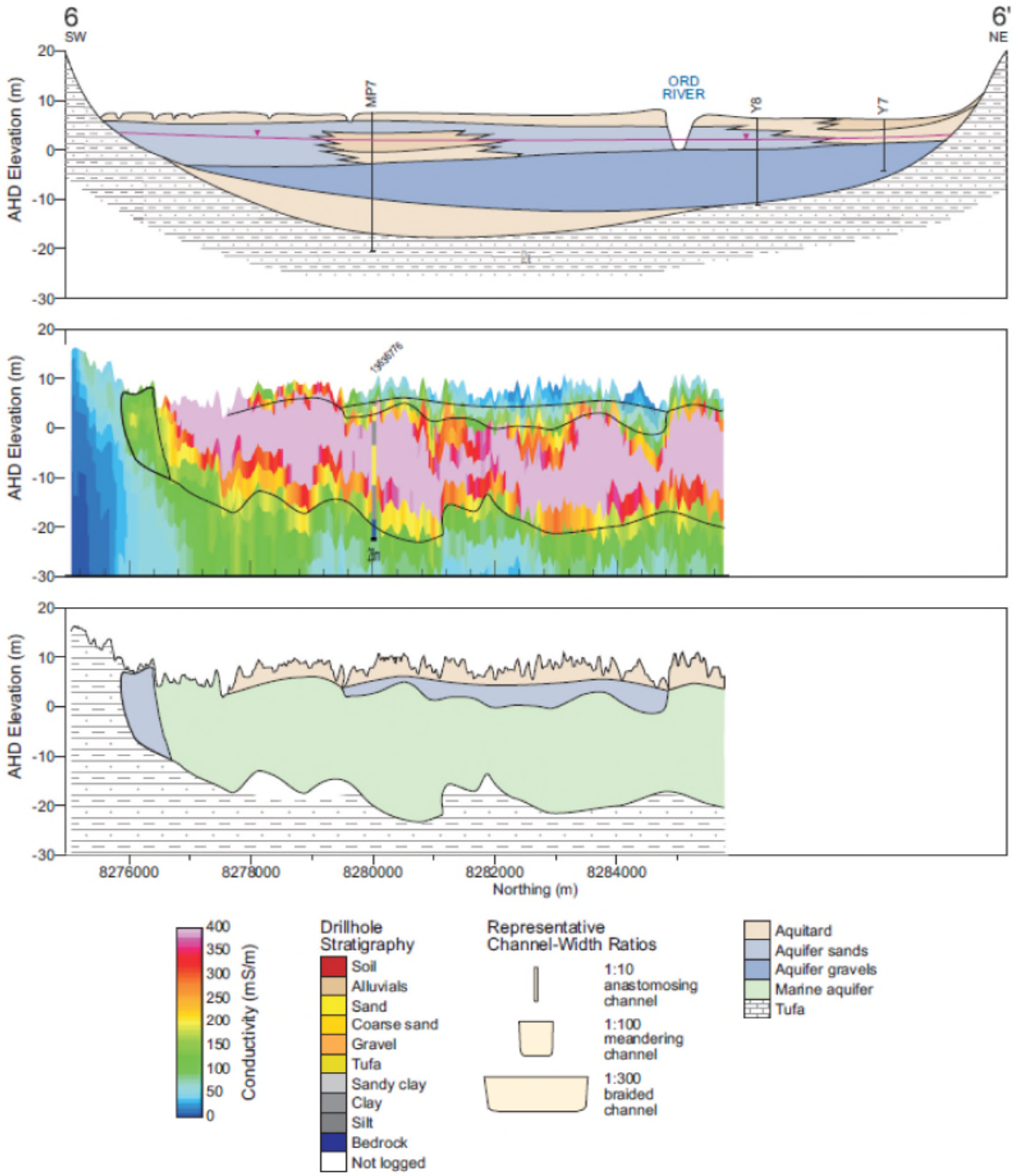


Figure 267: *Parry's Lagoon- Mantinea Plain- Carlton Hill cross section 6-6'. Top panel is cross-section from O'Boy et al., (2001); middle panel is synthetic AEM section showing drillholes colour coded for lithology and with lithology extent interpretation line work displayed; bottom panel is revised lithology interpretation produced in this study.*