Short-term groundwater dynamics at a paddock scale

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Abstract

For dryland agriculture in Australia to be sustainable, a well-defined linkage between shallow groundwater dynamics, particularly recharge, and land salinisation at a paddock scale is required. To help develop this, a 35 ha paddock in a dryland farm in southwestern Victoria, with a relief of only 6 m, was surveyed for electrical conductivity and instrumented with recording piezometers. The considerable spatial variability in EM31 conductivity across the paddock accurately reflected the soil and groundwater salinity, which were highest beneath the lowest elevation part of the paddock (a drainage line). The shallower watertable here is subject to greater evaporation and transpiration than other areas of the paddock with deeper watertables. After major rainfall events groundwater recharge is relatively uniform across the whole of the paddock, and the watertable rises sufficiently that the drainage line becomes a groundwater discharge zone. However, smaller rainfall events result in recharge only along the drainage line, which carries more water and is wetter for longer. Thus minor variations (a few metres) in surface relief across a farm affect the groundwater dynamics and cause significant variations in the salinity of the soil and groundwater. In particular, the area of highest salinity within the paddock is characterised by high rather than low recharge, in contrast to many other regions affected by dryland salinity in southeastern Australia. This has important ramifications for developing practical salinity management systems at the farm scale.

1. INTRODUCTION

To develop appropriate usage and management strategies in agricultural areas prone to dryland salinisation, land managers need spatially explicit groundwater and soil information at the paddock as well as catchment scale, because large variations in salt concentration can be present at a small scale even in a landscape of low relief (Williams *et al.*, 2001, 2006). Detailed field measurements of groundwater and soil salinity can be obtained using electromagnetic induction (EM) techniques, but without an understanding of the groundwater dynamics, particularly recharge, causing the variations in salinity, these measurements cannot be utilised to best effect in managing farm productivity.

A farm in southwestern Victoria (Fig. 1) was selected for detailed study. An electromagnetic (EM 31) survey showed substantial variation in electrical conductivity across the paddocks (Williams *et al.*, 2006). A single paddock was instrumented with a network of recording piezometers, to examine the dynamics of the underlying groundwater system in detail, and link this to the salinity variations across the paddock.

2. REGIONAL SETTING

The Willaura study site lies in southwestern Victoria (Fig. 1) and comprises flat undulating plains (240-260 mAHD) bounded by the Grampians ranges to the west. To the north is an elongated topographic low occupied by the permanent, saline Cockajemmy Lakes, fed by springs and shallow north-flowing drainage lines, one of which runs through the study site.

The geology consists of unconsolidated Quaternary colluvial/fluvial deposits overlying fractured Palaeozoic metasediments, with an extensive Quaternary basalt plain to the north.

The climate at Willaura is mild with a low mean annual rainfall of 524 (±105 SD) mm due to the presence of a rain shadow east of the Grampians. Rainfall is spread throughout the year and exceeds evaporation (1382 mm a year) from June to August. From 1996 to the present rainfall has been well below average; during the study period the paddock received only ~50 % of the average rainfall.

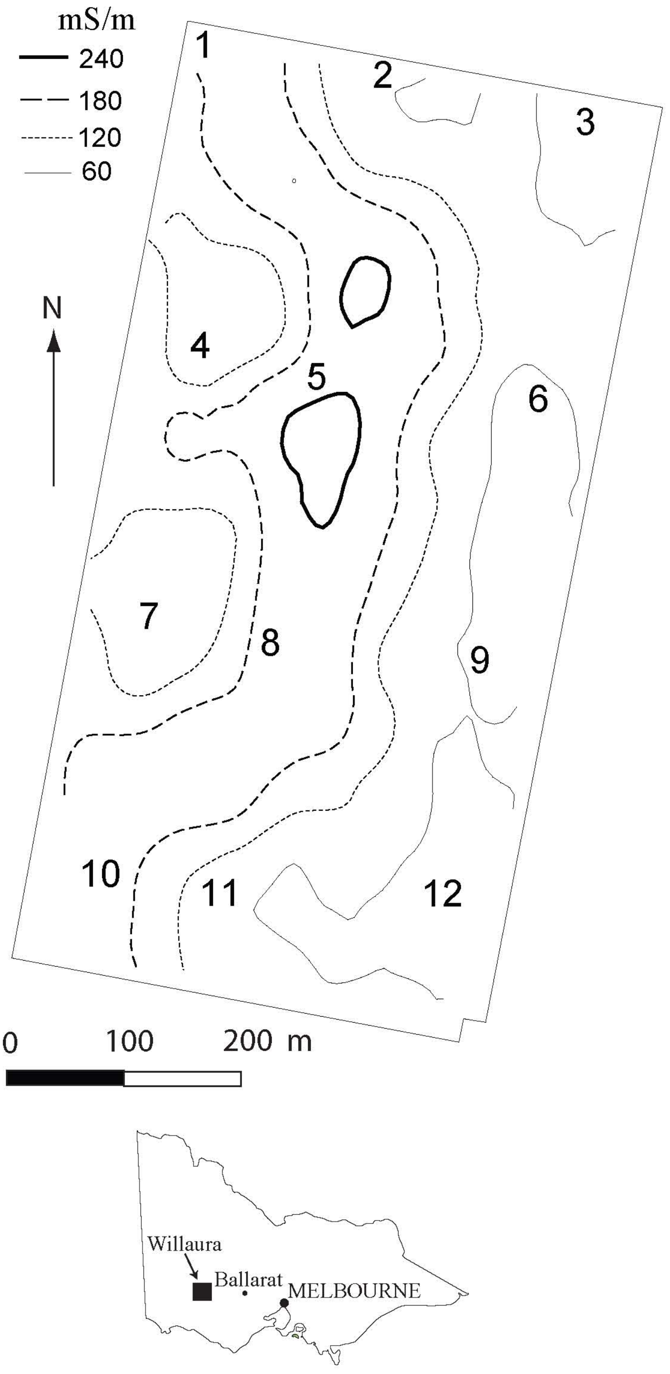

Figure 1 Location of piezometers on EM31 isoconductivity map of the study site

3. SITE DESCRIPTION

The paddock measures ~800 m by ~400 m (35 ha), and rises from north to south by 6 m. A drainage line runs from the SW to NW corners; the elevation difference between the centre of the channel and the paddock on either side is only 0.5-2 m.

The paddock has a long history of >50 years of cereal and pulse cropping. The lower section along the drainage line becomes waterlogged in wet seasons. Towards the beginning of the study period (August 2006) a pea crop was sown but failed at an early stage due to the drought, and until August 2007 the paddock had very little plant cover and was used for grazing.

4. METHODS

The paddock was surveyed topographically and by motorbike-mounted EM31; from the latter an isoconductivity map of the upper 5 m of the regolith was constructed (Fig. 1). Twelve piezometers ranging in depth from 4 m to 7 m were installed in March 2006, constructed from 50 mm PVC pipe slotted over the bottom 50 cm. The piezometers were equipped with Odyssey^{TM} capacitance water level recorders that took 3-hourly readings. A tipping bucket rain gauge recorded rainfall events >0.2 mm. Data was downloaded monthly; manual water level readings were taken at the same time. Soil profiles at each piezometer site were sampled in 50 cm increments and analysed for grain size (by hand texturing and Beckman Coulter Laser Particle Size Analyser) and EC on a 1:5 soil-water extract. Groundwater from all piezometers was measured for EC, temperature, pH and redox potential.

5. SOIL COMPOSITION

The soils generally consist of a surface layer of up to 50 cm of fine sandy/silty loam containing maghaemite gravel and up to 50-60% sand. At 1.5-2 m depth the soil becomes a heavier, compacted fine sandy/silty clay loam with 10-15% clay. In some profiles a layer of very hard, pale nodular calcite was encountered at ~1.5-3 m depth.

6. SOIL SALINITY

Soil salinity across the paddock varies spatially (Fig. 2), with a very good correlation between the EM31 conductivity to a depth of ~5m and soil EC1:5 to a depth of 2.5m (R^2 = 0. 985). There is ~10 times higher storage of soluble salts in the upper soil profile beneath the drainage line (maximum 2000 µS/cm; sites 5, 8 and 10 in Fig. 3) compared to the more elevated parts of the paddock (300 µS/cm beneath the eastern side). The higher soil salinity underneath the drainage line reduces crop yields in this area of the paddock.

The soil salinity is not related to soil texture or composition, but is inversely exponentially correlated with watertable depth (R^2 = 0.89), and increases greatly where the watertable is shallower than 3 m. In dryland areas of Australia evaporation and transpiration in the soil profile above the watertable increase sharply once the watertable is within 1.6 to 6.3 m of the soil surface, depending on the soil type (Peck, 1978; Ghassemi *et al.,* 1995; Salama *et al*., 1999). The increased evapotranspiration typically results in extensive salt accumulation, as in the study area where soil salinities are highest where the depth to groundwater is shallowest (<1.5-2.5 m) underneath the topographically lowest part of the paddock, the drainage line (Fig. 1). This effect is increased during wetter periods when the drainage line becomes waterlogged, and evaporation occurs virtually at the ground surface.

The more elevated parts of the paddock with low soil salinity represent areas of salt flushing. Small bulges in some of the soil salinity profiles here (Fig. 3) could reflect the recent severe drought conditions where rainfall events were too small to flush salt down to the watertable.

7. GROUNDWATER SALINITY

The average groundwater salinity is quite high (median 17 mS/cm), typical of the Willaura area (Bennetts *et al*., 2006). However, there is a remarkable spatial variation from 2 to 29 mS/cm over relatively short distances across the paddock (Fig. 2). Groundwater salinity closely matches soil electrical conductivity (R^2 = 0.91) and it too is inversely correlated with depth to watertable (R^2 = 0.73). The low salinity soil profiles across the more elevated parts of the paddock have been leached of salt and are underlain by relatively low salinity groundwater. By contrast, soils and groundwater in the lower parts of the landscape along the drainage line (sites 1, 5, 8 and 10; Fig. 2) are very saline, because, as explained previously, evapotranspiration from shallow groundwaters there concentrates salt in the soil profile. This salt is then leached downwards by infiltration events and also dissolves in the groundwater when the watertable rises as a consequence of recharge.

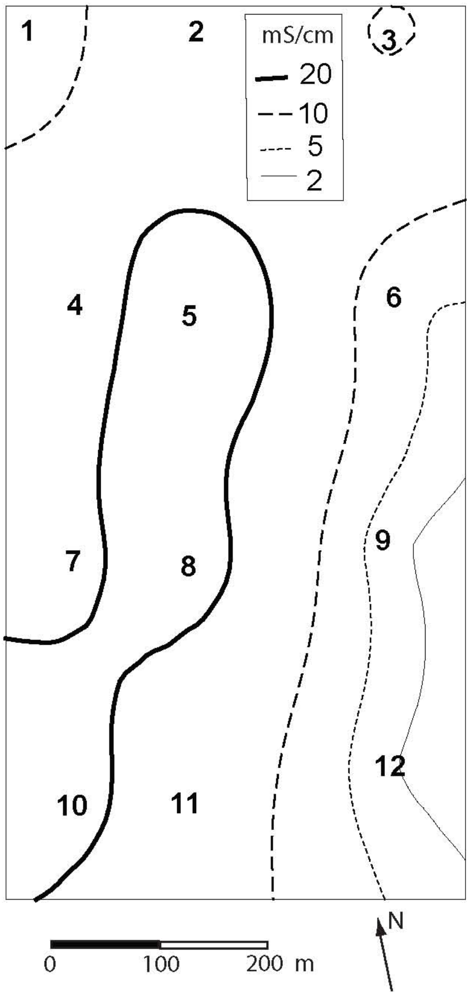

Figure 2 Electrical conductivity (EC) of groundwater

There was no temporal change in salinity over the time period of the study, indicating that groundwater composition is the result of slow, long-term processes.

8. GROUNDWATER FLOW AND RECHARGE

The watertable slopes gently and uniformly towards the north-northwest; groundwater flows in this direction to discharge in Cockajemmy Lakes.

Drought conditions persisted from the start of the investigation in March 2006 through to April 2007. Groundwater levels fell as much as 50 cm (Fig. 4) and the groundwater volume beneath the paddock decreased by ~6 ML (using a specific yield of 0.1). A similar volume of rainfall (120 mm) was received during this time, but little reached the watertable, because most was small showers apart from two significant rainfall events in mid July and late January. After both these events the groundwater level along the drainage line, but not beneath the main paddock area, showed a small increase that persisted for several months (Fig. 4). The rise was much greater in July (26 cm) than in January (2 cm), even though the July rainfall was less, because the monthly evaporation in July is much smaller

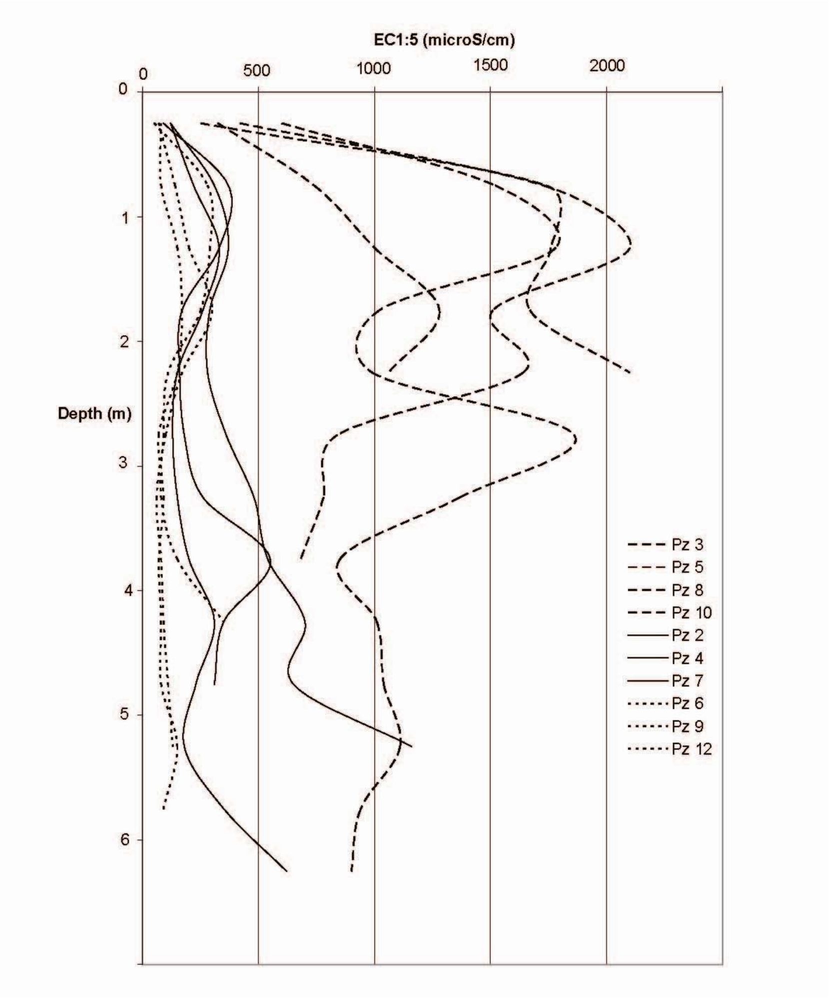

Figure 3 Soil salinity profiles

(45 mm compared to 205 mm). The majority of groundwater recharge in the Willaura catchment occurs in winter or shortly thereafter for this reason (Bennetts *et al.* 2006). The rainfall event in July arrested the decline in groundwater levels in some piezometers located away from the drainage line for 2-3 months, but from September onwards, water levels in all piezometers declined again due to the lack of rainfall.

However, two major rainfall events around 28th April and 26th May 2007 provided substantial recharge across the paddock (all loggers failed by early July but manual readings on August 19th showed the extent of the recharge). In the drainage line groundwater levels rose rapidly by ~750 mm after the first rainfall (Fig. 4), and were beginning to recede when the second wet period caused a further rise of ~700 mm, at which stage the piezometers became artesian (Fig. 5) and the drainage line was completely waterlogged. Beneath the main part of the paddock groundwater levels increased by only 100-200 mm after the initial rainfall, but rose substantially (up to 2.5 m) a few days after the second rainfall event, although the watertable remained 2.5-4 m below the ground surface (Figs 4,5). The watertable sloped away from the drainage line after the initial rainfall, but reversed to slope towards the drainage line as the whole paddock recharged following the second event (Fig. 5), and the drainage line changed from an area of groundwater recharge to discharge.

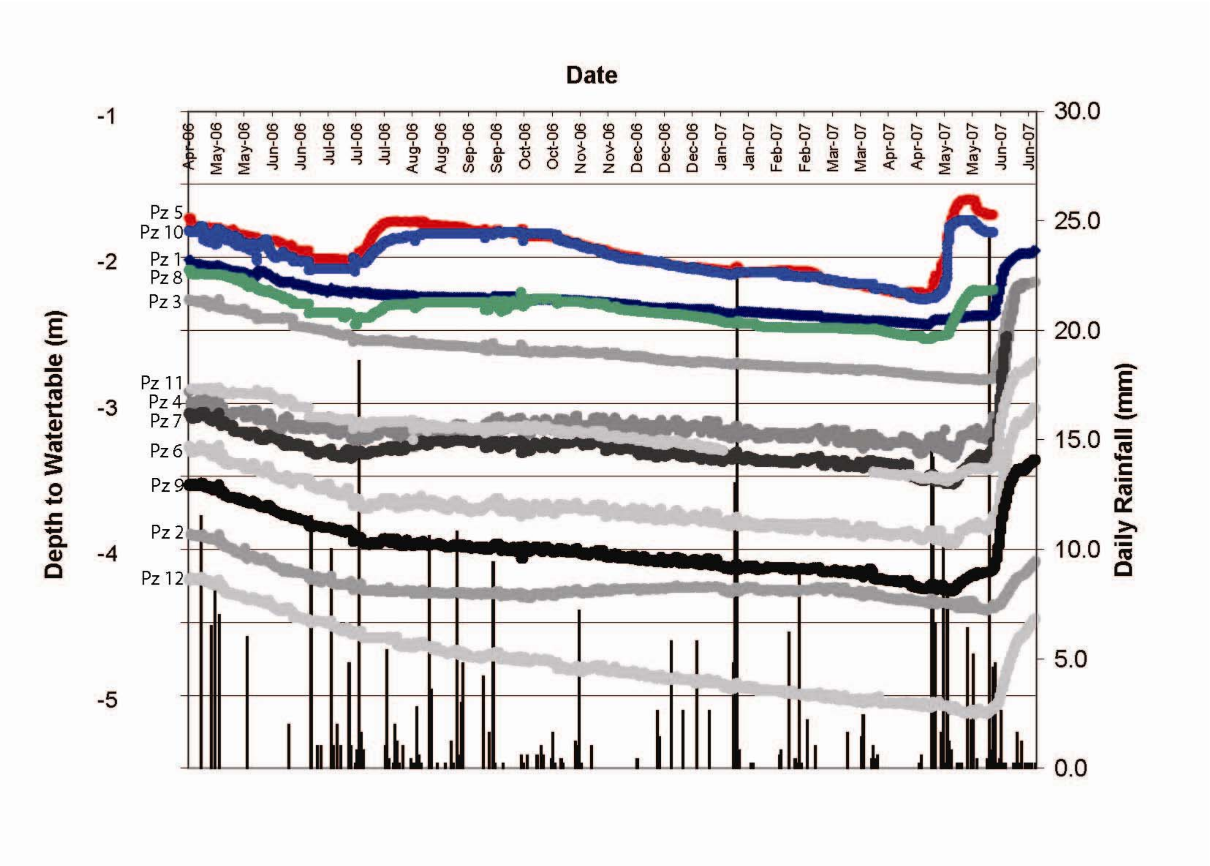

Figure 4 Groundwater hydrographs showing responses to rainfall events

Thus recharge occurs over the whole paddock following substantial rainfall, although the topographically lower drainage line changes from a recharge to discharge site as the watertable underlying the more elevated parts of the paddock rises. By contrast, smaller rainfall events result in recharge only along the drainage line, which carries more water and is wetter for longer. Similar dependence of soil moisture on topography has been demonstrated elsewhere in southeastern Australia (Western *et al*., 1999); the wettest areas lie along drainage lines after moderate rainfall, but are more evenly distributed across the catchment after heavier rainfall conditions.

9. RELATIONSHIP BETWEEN SALINITY, TOPOGRAPHY AND RECHARGE

In many areas of southeastern Australia subject to problems of dryland salinity there is a strong relationship between recharge and soil/groundwater salinity (e.g. Cook *et al*., 1989); areas of high recharge have relatively fresh soils and groundwater, due to flushing of salt through the system. Applying this relationship to the study site would suggest that the main part of the paddock had relatively high recharge, and the much more saline area along the drainage line was a zone of low recharge. However, the groundwater hydrographs (Fig. 4) show that the drainage line receives the most recharge, contradicting the general model.

The difference is due to the shallow watertable beneath the drainage line, so that evapotranspiration here concentrates salt in the soil and groundwater, as previously discussed. It is remarkable that the topographical relief within the paddock, even though it is only a few meters, is sufficient to cause differences in depth to watertable that result in large variations in salinity.

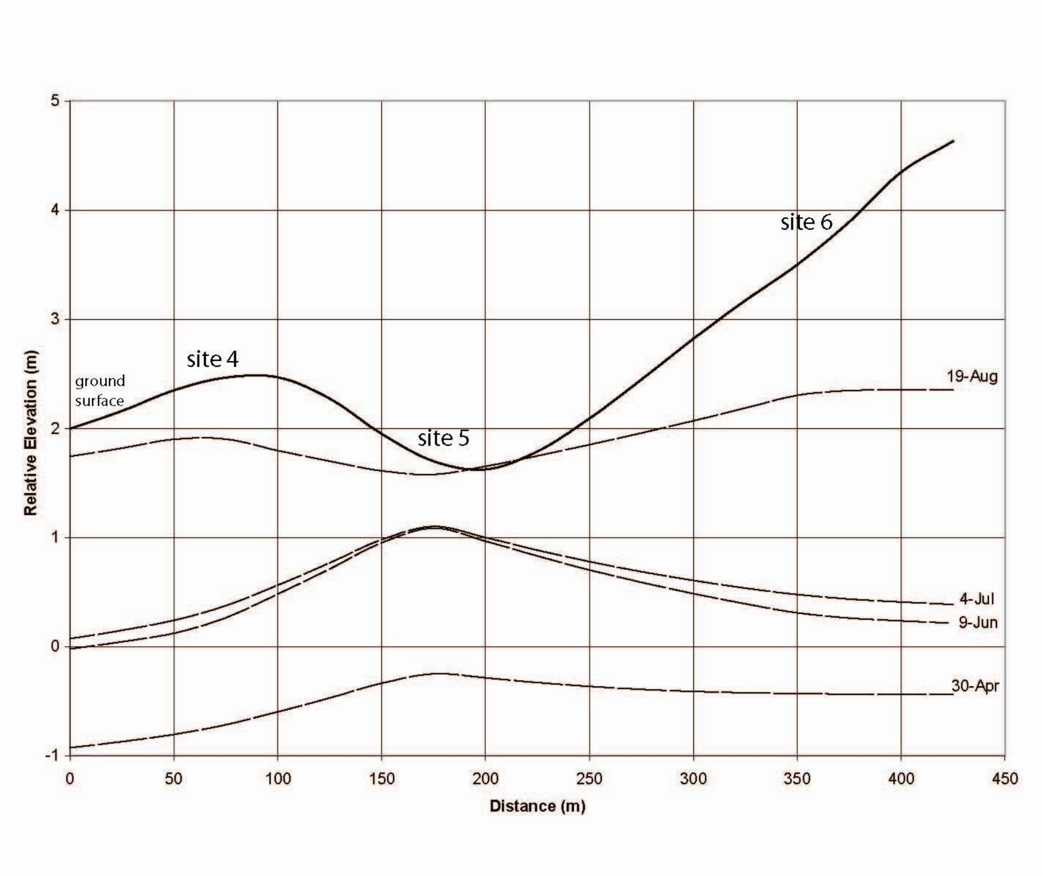

Figure 5 Cross-section showing response of watertable to July rainfall event

10. IMPLICATIONS FOR SUSTAINABLE LAND USE

The results of this study have important ramifications for developing practical salinity management systems at the farm scale. At the study site the EM31 map of soil conductivity provides an accurate picture of salt levels in both soil and groundwater, but accompanying knowledge of the watertable fluctuations is necessary to interpret the EM data in terms of recharge and salinity dynamics. In the Willaura paddock depth to the water table is the dominant factor causing groundwater and soil salinity, so that topographic lows are most susceptible to high salt levels. The higher elevation parts of the paddock are well leached of soluble salts and present no agronomic problems, but they do feed groundwater and salt to the topographic lows after major recharge events. Therefore management systems that decrease recharge would reduce salinity in the lower areas, e.g. agro-forestry, long-duration deep-rooting perennial pasture rotations and/or continuous cropping with stubble retention and minimum tillage in the off crop period, most usefully as mosaics across the landscape (Walker and Reddell, 2007). Vegetation cover is also necessary for soil protection.

In addition, a shallow spoon drain has been dug to enhance surface drainage from the paddock; this will shorten the residence time of water in the drainage line and therefore decrease groundwater recharge there, reducing the watertable rise during recharge events.

11. ACKNOWLEDGEMENTS

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