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Potential use of saline groundwater for irrigation in the Murray hydrogeological basin of Australia

Kemachandra Ranatunga*, Eloise R. Nation, Glynnis Barodien

Bureau of Rural Sciences, Department of Agriculture, Fisheries and Forestry, GPO Box 858, Canberra ACT 2601, Australia

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A B S T R A C T

Scarce surface water resources have led farmers to use groundwater heavily for irrigation in the Murray-Darling Basin of Australia. Saline groundwater is emerging as an alternative source of water for irrigation. This study examines the potential use of saline groundwater for a range of crops. Among cropping groups modelled, oilseeds and grain crops are considerably tolerant to saline groundwater in terms of the change yield with salinity levels, although the tolerance levels are crop-specific. Based on availability of saline groundwater, coarse textured soil, deep water table and moderate rainfall, this study also revealed that twenty-two percent or seven million hectares of the Murray hydrogeological basin in the southern Murray-Darling Basin may be suitable for the saline groundwater irrigation. However, it is also noted that the use of saline groundwater is only feasible for saline-tolerant crops under proper drainage management and by observing suitable precautionary measures. Therefore, the use of saline groundwater in irrigation requires careful attention to monitor the build up of salt in the root zone.

1. Introduction

Australia is the driest inhabited continent on Earth, with an average annual rainfall of approximately 455 mm/yr (Bureau of Meterology, 2008). The Australian climate is highly variable, characterised by severe droughts and floods. Consequently there is a natural scarcity of reliable water resources in Australia. A recent review of Australia's water resources (AWR, 2005) found that many of Australia's water management areas are over-allocated or highly developed, particularly in the Murray-Darling Basin. Where these water management areas are not highly developed, it is often only because the water is too saline or otherwise unsuitable to be used without first undergoing treatment.

The recent drought has placed additional pressure on water resources. Water restrictions were imposed in most major cities, irrigation allocations were significantly reduced in irrigation areas and agricultural production fell by 22.3% (ABARE, 2003). Climate change threatens to further reduce the availability of water resources. CSIRO recently conducted a review of current and future water availability in the Murray-Darling Basin (MDB). Various scenarios of climate change and development were considered as part of this study. The 'best estimate' results suggest that surface water availability could be reduced to 11% by 2030 (CSIRO, 2008).

This scarcity of water resources has prompted a search for alternative water sources. These water sources such as saline groundwater and grey water are not traditionally considered useable in Australia despite a considerable body of literature that has been developed regarding use of saline water for irrigation in the past two decades (Ben-Gal and Shani, 2002; Bingham et al., 1985; Bresler, 1987; Bresler and Hoffman, 1986; Letey et al., 1985; Letey and Dinar, 1986; Maas and Hoffman, 1977; Maas, 1990; Lamsal et al., 1999; Katerji et al., 2000; Shani and Dudley, 2001). Salinity is often expressed as a measure of Electrical Conductivity (EC) and the basic unit of measurement of EC is microSiemens per centimetre ($\mu S\ cm^{-1}$) or deciSiemens per meter ($dS\ m^{-1}$) as the basic units of measurement.

Large volumes of saline groundwater underlie much of rural Australia (NLWRA, 2001). It is one of the most promising alternative water sources in rural Australia potentially providing a reliable water source for irrigation, stock and domestic use. Saline groundwater is water that has more salt than fresh water, but not as much as seawater. Although the term saline has been used to describe groundwater with a range of salinities (Suttar, 1990; Patel et al., 2000), water in 500 and 30,000 $\mu S\ cm^{-1}$ salinity range is defined as saline groundwater in this study. Saline groundwater occurs in areas where the rainfall in low and is controlled by natural weathering and geological characteristics, such as marine sediments with high levels of residual salts (McWilliam, 1986).

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* Corresponding author at: Water Division, Bureau of Meteorology, GPO Box 2334, Canberra ACT 2600, Australia. Tel.: +61 (0)2 6232 3505; fax: +61 (0)2 6232 3500.

E-mail address: K.Ranatunga@bom.gov.au (K. Ranatunga).

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A salinity range up to 11,000 $\mu S\,cm^{-1}$ covers waters that can be applied to salt tolerant crops. As the salinity levels increase in soil with saline groundwater irrigation, the soil moisture potential decreases (Lamsal et al., 1999) through osmotic effects, which affect the crop yield. The salt tolerance of a crop depends on many factors, including the salinity level and the conditions in which the crop is growing (Maas and Hoffman, 1977; Maas, 1990). Salt tolerance can be evaluated by the fractional yield reduction from the water deficit imposed on a crop by salinity levels in the water. The higher the salinity, the lower the crop yield, evapotranspiration, pre-dawn water potential and stomatal conductance (Katerji et al., 2000). Crop tolerance to salinity ranges widely from the very salt-sensitive to the highly tolerant. Cotton, barley and sugar beat can tolerate up to 10 times as much salt as most clover, beans and fruit trees. Typical salinity tolerance and susceptibility are given in Table 1 for major crops grown in Australia.

Although saline water in high salinity levels may have effects on crop growth, if the soil is loamy in texture and the water table is deep, the conditions are less hostile for crops. The availability of good quality water for supplementary irrigation or considerable rainfall is required during the initial establishment phase and for periodical leaching of salts from the root zone.

2. Objectives

The main objective of this study is to assess the potential use of saline groundwater for irrigation in the Murray hydrogeological basin within MDB. This objective is achieved through two specific aims. Firstly the potential impact of saline groundwater irrigation on major crops grown in the basin is investigated. Secondly areas within the basin where suitable levels of saline groundwater are available for irrigation are identified.

Table 1
The area of the major crops (Source ABS AgStats in 2006) and salinity tolerance.

Crops	Cropping area (million ha)	Threshold salinity levels (ECe in μS/cm)	Reference
Cereals			
Wheat	12.34	4700	Kotuby-Amacher et al., 1997
Barley	4.41	8000	Hassan et al., 1970
Grain sorghum	0.76	6800	Francois et al., 1984
Oats	0.94	5200	Kotuby-Amacher et al., 1997
Triticale	0.35	6100	Francois et al., 1988
Rice	0.10	3000	Venkateswarlu et al., 1972
Maize	0.07	2700	Kotuby-Amacher et al., 1997
Pulses			
Field peas	0.28	1000	Kotuby-Amacher et al., 1997
Faba beans	0.18	1600	Ayars and Eberhard, 1960
Oilseeds			
Canola	0.93	11,000	Francois, 1994
Sunflower	0.08	4800	Francois, 1996
Other crops			
Sugarcane	0.40	1700	Syed and El-Swaify, 1972
Cotton	0.31	7700	Bernstein and Ford, 1959
Grapes	0.15	1500	Taha et al., 1972

3. Study area description

The Ouyen region located in the Victorian Mallee within the Murray hydrogeological basin was chosen as the study area (Fig. 1). The landuse of the Victorian Mallee is predominantly non-irrigated agriculture, including growing wheat and barley as well as pastures. Irrigated agriculture in this region includes grapes, fruits, olives, citrus and vegetables. This region has winter-dominant rainfall with an annual average of 330 mm. The average rainfall during the growing season is around 185 mm. Although the average winter temperature allows considerable growth of crops and pastures, the optimum temperatures for growth typically occur in the early autumn and late spring. Crops are grown during the cooler and wetter part of the year. The annual cereals are sown during autumn and early winter and harvested in early summer. Spring irrigation of canola and field peas is needed earlier than for wheat and barley. Continuous cropping is uncommon in areas with rainfall <350 mm year (Cook et al., 2001).

The range of soil texture varies from sands to clays. The soil and water characteristics of the Ouyen region were taken from Cock (1985). Water holding capacity (WHC) varies between 30 mm/m and 60 mm/m for soil textured between 2% to 15% clay and as the clay content increases to 25%, WHC increases to 80 mm/m. Cook et al. (2001) have recently reviewed dryland processes in the Mallee. A reasonably constant value of WHC (60 mm/m) for areas with sandy and sandy loam textured soils was adopted in this study consistent with those reported in Cook et al. (2001).

4. Methods

To satisfy the objectives of this study, a crop water model is needed with the ability to simulate yield and evapotranspiration (ET) of different crops with varying salinity levels in the irrigation water. Based on the expert opinion gathered from the authors of the model, the EPIC (Environmental Policy Integrated Climate, originally known as Erosion Productivity Impact Calculator) modelling framework (Williams et al., 1984) was chosen for this study. EPIC was developed by USDA-ARS in cooperation with the Texas Agricultural Experimental Station. EPIC is a public domain model that has been used in over 60 different countries in Asia, South and North Americas and Europe. Williams et al. (1989) tested EPIC against the yields of various grain and legume crops including wheat at several locations in the United States and at sites around the world, and concluded that simulated and measured yields were in good agreements. The EPIC model predicts the effects of management decisions on soil, water, nutrient and pesticide movements and their combined impact on soil loss, water quality and crop yield for areas with homogeneous soils and management. Most of the yield-salt functions in EPIC are based on the dependence of biomass production on transpiration with saline conditions taken from Maas and Hoffman (1977), Bresler et al. (1982) and Bresler (1987). The salinity conditions in yield-salt functions are related to soil water salinity in the root zone.

The mapping of groundwater salinity was produced using available data to identify the location and availability of saline groundwater in the MDB. The data used in this analysis are monitoring bore data, Groundwater Management Units (GMU) as defined by NLWRA (2001), stream connectivity and groundwater salinity contours. Bore data (groundwater salinity and metadata) were collated in a bore database and used to produce a GIS dataset as shown in Fig. 2. The GMU delineated by NLWRA (NLWRA, 2001) was selected as the key spatial unit because they are spatially explicit representation of management areas for groundwater. It is one of the national datasets which represents groundwater systems and has been used in other water assessment studies (NLWRA, 2001; AWR, 2005). All the GMUs used in the analysis were assigned a depth range to enable selection of bores of appropriate depth for each GMU before interpolating a groundwater salinity surface for each of them. A GIS dataset of stream connectivity was also used as an input to the interpolation of groundwater salinity for surficial aquifers. The dataset was created specifically for this project using five million scale national stream data for the MDB in order to identify. Where streams are 'gaining' and 'losing' in terms of the groundwater/surface water interactions. The 'losing' field was populated with the 50th percentile of all stream salinity data and 'gaining' field was given the 80th percentile of stream salinity data (MDBMC, 2006). Shallow salinity contours of the Murray and Darling Basins (salinity contours) were used as the basis for interpolating the groundwater salinity of shallow GMUs with good coverage of contour data and where bore coverage was poor. The individual salinity surfaces were created using a series of geo-processing workflow models in ArcGIS Model Builder using bore data. The estimation of saline groundwater volumes is reported in detail elsewhere (Nation et al., 2009).