On-farm options for managing stream salinity in irrigation areas: an example from the Murray Darling Basin, Australia

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ABSTRACT

Increasing salt concentration in tributaries from catchments and rising water tables are the prime contributor to environmental degradation of rivers, creeks, streams or other water bodies. This is especially true during periods of mid- and low stream flows in arid and semi-arid regions around the globe. Catchment scale studies suggest that management of stream salinity requires greater land use change than is economically viable. Therefore, rather than focusing on the opportunity cost of catchment scale interventions, exploring interventions that are potentially viable at farm scale could be an appropriate strategy for stream salinity management. This paper presents an analysis of alternative on-farm strategies, such as evaporation ponds and serial biological concentration of salts, aimed at developing an economically self-sustainable stream salinity management system for the Box Creek stormwater escape channel located in the Murray–Darling Basin (MDB), Australia. It is concluded that irrigation areas, with careful management of flows in tributary streams, may be able to play a role in safeguarding the Murray River against further salinisation from irrigation and dryland areas. The outcomes of this paper will be helpful, but not limited to, the MDB in addressing environmental, economic and social issues associated with management of salt concentration in tributaries.

Key words | Australia, evaporation ponds, salt concentration, serial biological concentration of salts, stream flows, stream salinity

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INTRODUCTION

There are several factors affecting salt concentration in stream flows, including clearing of deep-rooted natural vegetation from catchments, replacing them with shallow-rooted agricultural crops, increasing diversions from inflow streams for irrigation, discharging of saline agricultural drainage and/or rising saline water tables in the adjacent areas (Williams 2001). Increasing salt concentration during periods of mid- and low flows in arid and semi-arid regions (mean annual rainfall 25–500 mm) is a prime contributor to environmental degradation of rivers, creeks, streams or other water bodies. These (semi-) arid regions cover about one-third of the total globe land mass and spread across parts of Central America, South America, North America, the Middle East, South Asia, Central Asia and Australia. In these regions, there is considerable environmental and social pressure to reduce salt concentration in rivers (Blackmore *et al.* 1999).

Specifically in irrigated areas, tributary streams generally carry rainfall runoff from catchments, escape water from irrigation areas and groundwater inflows. Rainfall runoff from inland catchments and escape water from irrigated land areas are normally of low salinity: however, groundwater inflows are usually of high salinity. The salinity of different kinds of inflows actually defines the overall salinity in the streams and/or rivers. In Central Asia, escape water from irrigated areas makes up to 30% of flows in Syr Darya and Amu Darya (Kurbanbaev *et al.* 2002). As a result,

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the mean annual salinity of the river flow reaches 1.25–2.50 decisiemens per metre (dS/m) in Amu Darya and 2.00–3.00 dS/m in the Syr Darya, even though Syr Darya flows are generally higher than flows in the Amu Darya (Letolle & Chesterikoff 1999). Such a high salinity in these two rivers is responsible for increasingly serious environmental, economic and social consequences in the Central Asian region.

Preventive and remedial strategies are used to manage salt concentration in stream flows at the catchment and farm scales, particularly in the dryland areas of Australia (Herron *et al.* 2002; Beverly *et al.* 2003; Cresswell *et al.* 2003; van Bueren & Price 2004). The aim of preventive strategies is to prevent further increase in salt concentration by decreasing discharges of salt from catchments further from surface flow or rising water tables. The aim of remedial strategies is to decrease or at least stabilize salt concentration in flows and to manage saline agricultural wastewater discharges. Catchment scale studies suggest that management of stream salinity requires greater land use change than is economically viable (Herron *et al.* 2003; Tuteja *et al.* 2003). Therefore, rather than focusing on the opportunity cost of catchment scale interventions, exploring interventions that are potentially viable at farm scale could be an appropriate strategy for stream salinity management (Nordblom *et al.* 2004; Lefroy *et al.* 2005).

In the Murray–Darling Basin (MDB), the Land and Water Management Plans (LWMPs), designed using both preventive and remedial strategies for managing salt concentration from irrigated areas, are being widely implemented in different states. For the implementation of these LWMPs, each state will receive salinity credits of 15 electrical conductivity (EC) units. In the NSW Murray Irrigation, Murray Irrigation Limited (MIL) is the implementation authority for the Murray LWMPs. For the implementation of these LWMPs, MIL will receive five EC credits. A state or irrigation company receives a salinity credit for any works or measures that reduce average salinity in the lower reaches of the Murray River (i.e. at Morgan) by more than 0.1 EC and a salinity debit for any works or measures that increase average salinity at Morgan by more than 0.1 EC. The salinity credit or debit is equal to the expected decrease or increase in salinity. Therefore, each state or irrigation company must remain in salinity credit to ensure that they do not contribute to an increase in salinity at Morgan.

In Australia, water salinity is normally reported in EC units, which is equivalent to microsiemens per centimetre (μS/cm), as an indicator of the concentration of salts dissolved in water. Thus, by dividing the EC unit by 1,000, water salinity can be referred to as dS/m. However, the relationship between EC and water salinity varies, depending on which salts are present in solution. An understanding of what the salt mix is for a particular water body is necessary to convert EC to salt concentration in milligrams per litre (mg/L) accurately, so that we can calculate salt load. The most common conversion factor is between 0.6 and 0.68, i.e. EC (μS/cm) $\times 0.64 =$ salt concentration in water (mg/L). Salt load, which is calculated from stream flows and the respective salinity data, is a measure of the quantity of salt that passes a particular monitoring point during a specified period of time. Salt load is often expressed in tonnes/day or tonnes/year.

Duncan *et al.* (2005) reviewed previous studies of salt mobilisation processes and management strategies in the irrigation areas of Australia. For instance, to improve the environmental management of the Box Creek Stormwater Escape Channel (SEC), a number of alternative solutions including hydraulic, hydrogeologic, water quality treatment, vegetation management and water harvesting have been considered (URS 2003). However, there has not been any significant breakthrough in developing cost-effective on-farm salinity management alternatives, especially for irrigated areas. As a part of the hydro-economic feasibility study of developing on-farm options for managing stream salinity in irrigation areas, this paper discusses the following:

- hydrological assessment to find out the quantity of salt load (tonnes/year) that would possibly be taken out from the Box Creek SEC to reduce the stream salinity, and
- economic assessment of establishing evaporation ponds and Serial Biological Concentration (SBC) of salts at a suitable farm location that could cost-effectively use the separated saline water.

STUDY AREA

Figure 1 presents the location of the study area – the Box Creek SEC, Murray Irrigation, New South Wales (NSW), in the MDB, Australia. The Box Creek SEC was constructed in

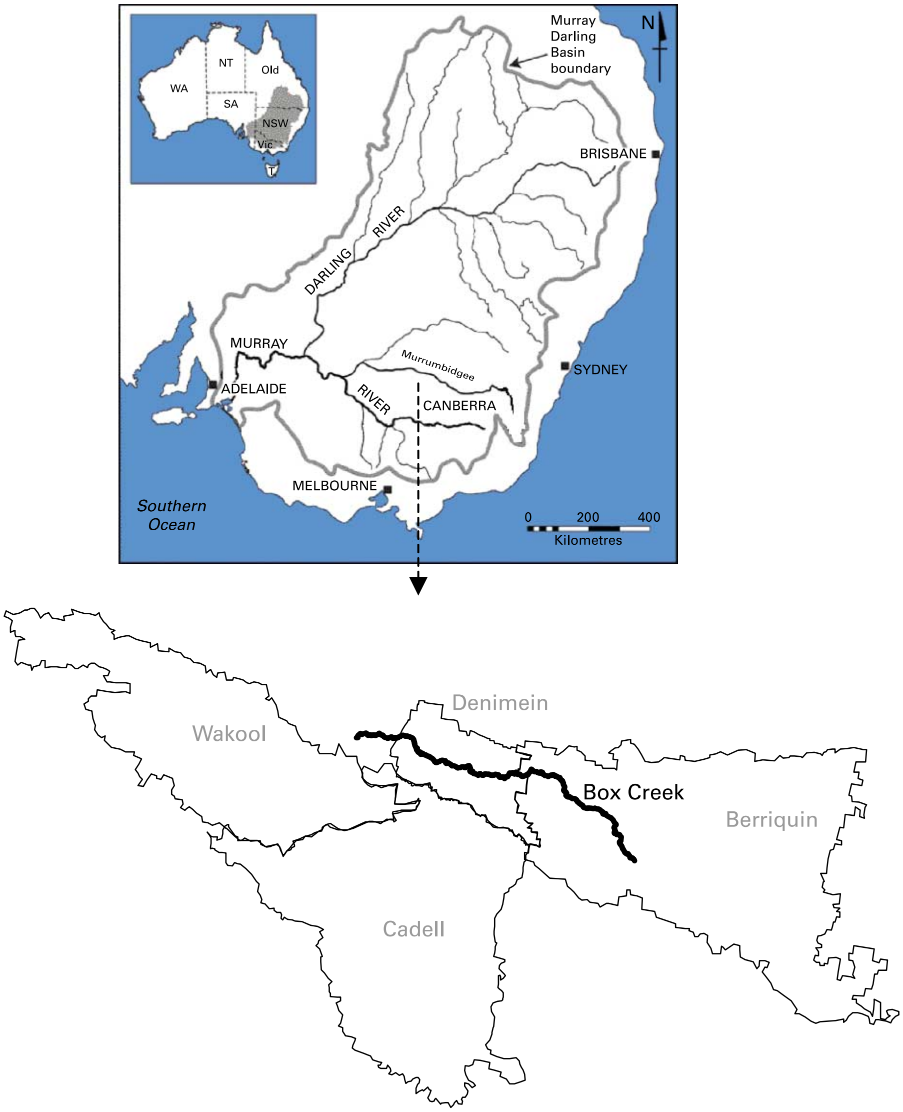

Figure 1 | Location map of the study area.

the early 1950s to provide an outlet for stormwater and agricultural drainage from the Berriquin and Denimein irrigation districts. The Box Creek SEC flows in a westerly direction through both the Berriquin and Denimein Irrigation Districts.

The Box Creek SEC, which is 133 km long, is an integral component of the Murray Irrigation Limited (MIL) supply and stormwater system. Its catchment is in excess of 50,000 hectares (ha) and receives flows from eight other SECs as well as 16 supply channel escapes. The MIL is responsible for improving the environmental management of the Box Creek SEC starting from downstream of the Riverina Highway to Barratta Weir. This section of the Box Creek SEC is approximately 39 km long. After passing this weir, the Box Creek SEC flows enter the Edward River.

Climate

Figure 2 presents climatic conditions observed from July 1889 to June 2005 at Finley (Meteorological Station no. 74,093, latitude 35.57 S and longitude 145.53 E) located in the upper catchment area of the Box Creek SEC. Historical climate data (from July 1889 to June 2005) was used to define the average daily climatic conditions in the study area. Accordingly, if

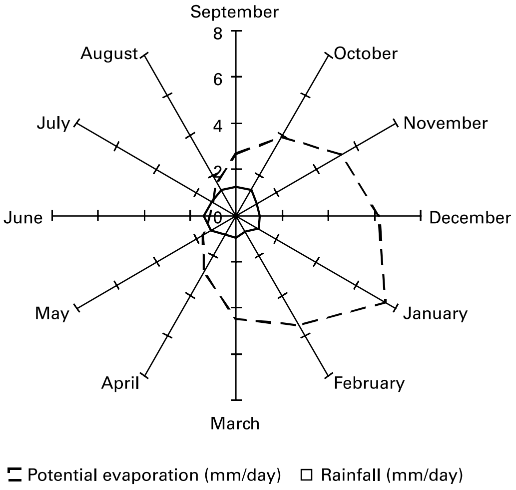

Figure 2 | Average daily rainfall and potential evaporation in the study area.

potential evaporation is compared with rainfall, a water deficit exists from August till May, which necessitates irrigation for growing crops. For the months of June and July, rainfall equals potential evaporation and therefore there is very little irrigation requirement. Using the long-term climatic data (July 1889–June 2005), deciles analysis (Gibbs & Maher 1967) was conducted to define annual rainfall during dry (1st decile), average (5th decile) and wet (9th decile) climatic conditions. As a result, the annual rainfall during dry, average and wet climatic conditions was estimated around 273, 402 and 576 mm, respectively. While comparing the actual observed rainfall in the study area during July 1997 to June 2005 with long-term climatic conditions, the lowest rainfall was observed during July 2002–June 2003 (250 mm), and the highest rainfall was observed during July 1999–June 2000 (450 mm). Thus, the study period (July 1997–June 2005) represents climatic conditions when average annual rainfall (373 mm) was below average.

Hydrology

In this study, the data on stream flows and their respective salinity levels observed on a daily basis at the BOXC from June 1997 to September 2005, which is the only historic data monitoring site on the Box Creek SEC, was used. Generally, salinity levels during high flows in the Box Creek SEC (due to irrigation and/or rainfall seasons) were observed around 1.30 dS/m. However, during the low stream flows, salinity levels were observed higher than 5.20 dS/m. The correlation analysis (not presented here) indicates a negative relation between stream flows and their respective salinity levels. When stream flows are low, the stream salinity becomes high.

A percentile analysis of this daily observed data was carried out to describe the probability of stream flows and their respective salinity levels (Table 1). There was a 90% probability that stream flows would not go below 1.77 ML/d, and 10% probability of stream flows exceeding 30.58 ML/d. Similarly, there was a 90% probability that stream salinity would not exceed 8.3 dS/m, and there was a 10% probability of stream salinity being below 1.4 dS/m.

Issues

The current problem of the Box Creek SEC, as indicated from the historic stream flows and the respective salinity records, is that it is deteriorating in quality with respect to salinity and nitrogen. However, turbidity and phosphorus are found to be within acceptable ranges. As a condition of Murray Irrigation's Water Management Works Licence, water that flows from the Box Creek SEC into the Edward River must not increase the salinity of water in the Edward River to more than 0.80 dS/m.

Although the contribution of flow from Box Creek SEC is fairly low (approximately 7%) relative to the total flows leaving the Murray Irrigation, it contributes significantly (approximately 45%) to the total salt concentration that leaves the Murray Irrigation. Therefore, salinity management

Table 1 | Probability analysis of flows and their respective salinity at BOXC monitoring point on the Box Creek Stormwater Escape Channel

Percentile	Stream flows (ML/d)	Salinity (dS/m)
0%	0.004	26.7
10%	1.77	8.3
20%	2.96	6.3
30%	4.34	5.1
40%	5.70	4.2
50%	7.68	3.6
60%	9.88	3.1
70%	13.77	2.4
80%	18.92	1.9
90%	30.58	1.4
100%	184.60	0.3

of the Box Creek SEC flows will have a significant impact on achieving salinity benefits for the Murray River.

OVERVIEW OF SALINITY MANAGEMENT OPTIONS

To prioritise on-farm options for managing salinity in the Box Creek SEC, several factors such as the quantity and quality of groundwater entering the creek, possible investments, operation and maintenance requirements, social acceptance and geophysical settings must be considered. The environmental gains against the possible capital investment costs and sociophysical concerns would be a key to prioritising the options.

There are many ways of capturing saline groundwater flows before they enter the surface water bodies, such as installation of vertical (e.g. shallow tubewells) or horizontal (e.g. subsurface interceptors) drainage systems alongside the creek. The operation of vertical or horizontal drainage systems could induce seepage losses out off the creek flows, which could aggravate the surface water quality concerns, and would also lead to excessive operational costs (Bhutta *et al.* 1996; Farrington & Salama 1996; Beltran 1997; Wolters & Bhutta 1997).

On the grounds of simplicity, technical efficacy and potential cost-effectiveness, alternative options such as: (i) constructing weirs in different reaches of the creek and (ii) pumping water directly from the creek may be considered. By constructing weirs in different reaches of the creek, the ponding of surface water will develop a hydraulic gradient away from the creek, thereby preventing groundwater flows into the Box Creek SEC. To avoid obstruction to the normal creek flows, these weirs should not be permanently raised structures: thus, triggering type weirs with a lowering and raising mechanism may be used. However, the feasibility assessment of this option is not within the scope of this paper.

Therefore, pumping water directly from the creek was considered appropriate as a measure of managing stream salinity in the Box Creek SEC. Lee (1993) provides an overview of different alternative for treatment, reuse and disposal of such high salinity water. However, in the context of geo-hydrological and agro-climatic conditions in the study area, evaporation ponds and an SBC system (Figure 3) were selected for making productive use of pumped water at a suitable community farm location.

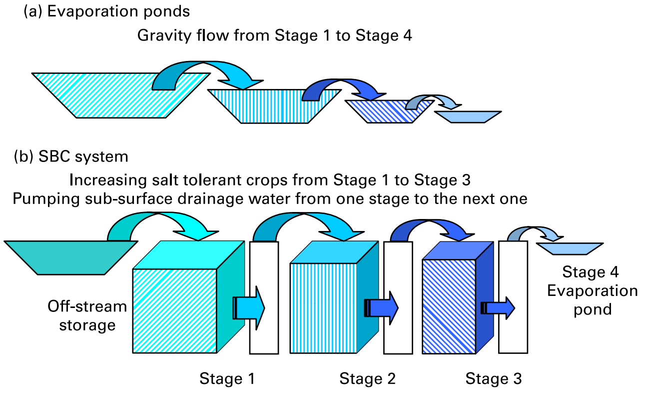

Figure 3 | Conceptual diagram of on-farm salinity management options: (a) evaporation ponds and (b) SBC system.

Evaporation ponds

In the Box Creek catchment, average annual pan evaporation is 1851.57 mm compared with 384.09 mm rainfall. Therefore, one hectare of evaporation pond can potentially evaporate an average of 14.67 ML annually. Therefore, to annually evaporate 330 ML of the separated saline water from the Box Creek SEC, four evaporation ponds totalling 22.0 ha would be required. Water salinity increases due to open surface evaporation: thus, these ponds have different sizes (11, 7.0, 3.2 and 0.8 ha) for managing water of different salt concentrations. Pumped water from the Box Creek SEC will be put into the first evaporation pond (11 ha), then it will moved with gravity flow through pipes to the next level pond(s). Evaporation ponds can be a convenient and economic option in areas which have high evaporative demand and have an abundance of natural depressions far from the cultivated lands.

Although evaporation ponds (with or without harvesting salts) is an accepted practice in many countries (Evans 1990; Trewhella & Badruddin 1991; Micklin 1992; Tanji *et al.* 1993), seepage losses, loss of land, cost of construction and management, and environmental concerns (e.g. groundwater pollution and exposure of wildlife to toxic elements in the ponds) are the major limiting factors (Sharma & Tyagi 2004). The presence of toxic trace elements, cost of transportation and treatment may constrain one to harvest salts from these ponds as a marketable produce. Information on pond water chemistry and mineralogy is required to assess the potential reuse of pond waters and the extent of chemical and biological immobilization of toxic elements (Johnston *et al.* 1997).

SBC system

Khan *et al.* (2007*a*) provides detailed information on the concept and hydrogeological assessment of the SBC system to manage saline water in an Australian context. With additional off-stream storage of 300 ML capacity, three stages of the SBC system and an evaporation pond are considered in this study. The off-stream storage was decided to meet the irrigation water requirements of Stage 1 of the SBC system.

Each stage will have saline agriculture made viable with the help of a subsurface drainage system. Stage 1 receives water from this storage and a sub-surface drainage below the root zone from Stage 1 would then be captured and supplied to Stage 2. The same processes would be repeated for the rest of the stages for growing increasingly salinity tolerant crops until finally discharging into an evaporation pond.

Under the agro-climatic conditions in the Box Creek catchment, perennial pasture like Lucerne (threshold salinity value, $EC_{se} = 2.5$ dS/m, slope of yield reduction per unit of increase in salinity of the saturated soil extract = 4%, salinity of irrigation water, $EC_{iw} = 1.83$ dS/m) could be grown on 30 ha in Stage 1. In Stage 2 (10 ha), perennial pasture like rye grass could be grown ($EC_{se} = 5.6$ dS/m, Slope 7.6%, $EC_{iw} = 4.1$ dS/m). In Stage 3, very tolerant crops (e.g. salt bush) could be included on 4 ha. Drainage water from Stage 2, which will have a salinity level around 12 dS/m, will feed these salt bushes. An evaporation pond of 0.8 ha was included, which will receive saline water of around 50 dS/m from Stage 3.

The sub-surface drainage or leaching fraction was notionally considered one-third of the applied water (Su *et al.* 2005), which may not be an achievable target under many field conditions. For instance, where an impermeable layer underneath the sub-surface drainage system does not exist at a shallower depth, or where substantial lateral groundwater flows occur towards the sub-surface drainage area, or in aquifers where deep groundwater flows are also effectively occurring (Ayars *et al.* 2006). Therefore, for appropriate designing of the sub-surface drainage system, detailed geo-technical investigations play an important role, for instance, for defining the depth of impermeable layer underlying the sub-surface drainage system (Singh *et al.* 2006) and in establishing the hydrological setting for the proposed site (Su *et al.* 2005; Khan *et al.* 2007*a*).

In both the Berriquin and Denimein irrigation districts, 40% of the area was under irrigated crops. The inactive landuse occupies around 8% of the landscape in these two districts. Along the Box Creek SEC, a total of 1462 ha was lying as permanently inactive landuse, whereas around 5856 ha were permanently dryland during 2000–01. These inactive and dryland areas present an opportunity for developing a community farm that would help in making productive use of pumped water to achieve salinity credits for the Box Creek catchment. If the selected area is already laid out to irrigation, it will minimise the field work required to set up for the SBC system.

HYDROLOGICAL ANALYSIS OF STREAM FLOWS

Using the data on stream flows and their respective salinity levels observed on a daily basis at the BOXC from June 1997 to September 2005, hydrological analysis of stream flows was carried out. In the case of evaporation ponds and the SBC system, the purpose of such an analysis is to find out the quantity of salt load (tonnes/year) that would possibly be taken out from the Box Creek SEC to reduce the stream salinity.

Evaporation ponds

Although low irrigation diversions and below-average rainfall were observed during July 1997 to June 2005 (Figure 4), still there were a considerable number of days when creek flows were greater than 1.77 ML/d (Figure 5). When daily stream flows are greater than 1.77 ML/d, 443 ML/yr of saline water would be available for evaporation ponds with 1.77 ML/d of pumping from the Box Creek SEC during the driest year of July 2002–June 2003, with an average of 579 ML/yr during July 1997–June 2005.

Accordingly, depending upon the salt concentration in stream flows, there would be a different potential for salts harvesting using the 300 ML capacity of evaporation ponds during July 1997 to June 2005. A total of 874 t/yr of salt load would be harvested during the driest year of July 2002–June 2003 due to the highest salt concentration (i.e. 2.91 t/ML), with an average salt load of 781 t/yr during July 1997 to June 2005.

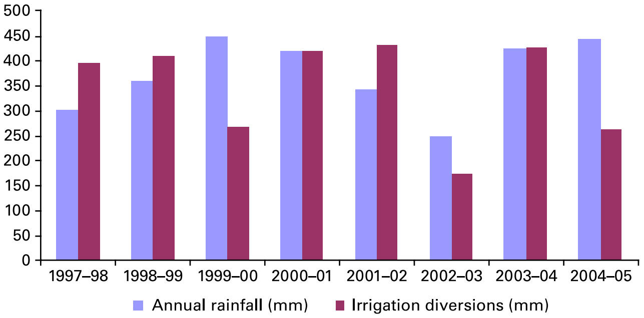

Figure 4 | Annual rainfall and irrigation diversions from July 1997 to June 2005 in the study area.

SBC system

As mentioned earlier, if perennial pasture like Lucerne is to be grown under the agro-climatic conditions in the Box Creek catchment, the salinity of irrigation water should be around 2.5 dS/m. However, when salinity levels of the off-stream storage with 1.77 ML/d pumping were estimated, it becomes around 4.1 dS/m on average. But with 25% pumping of actual flows when stream flows were greater than 1.77 ML/d, then the salinity levels of the off-stream storage become favourable for growing perennial pasture at Stage 1.

When daily stream flows are greater than 1.77 ML/d, 336 ML/yr of saline water would be available for the SBC system with 25% pumping of actual flows in the Box Creek SEC during the driest year of July 2002–June 2003, with an average of 1367 ML/yr during July 1997–June 2005. Accordingly, depending upon the salt concentration in stream flows, there would be a different potential for salts harvesting using the 300 ML capacity of the off-stream storage during July 1997 to June 2005. A total of 560 t/yr of salt load would be harvested during the driest year of July 2002–June 2003 due to the highest salt concentration (i.e. 1.87 t/ML), with an average salt load of 513 t/yr during July 1997 to June 2005.

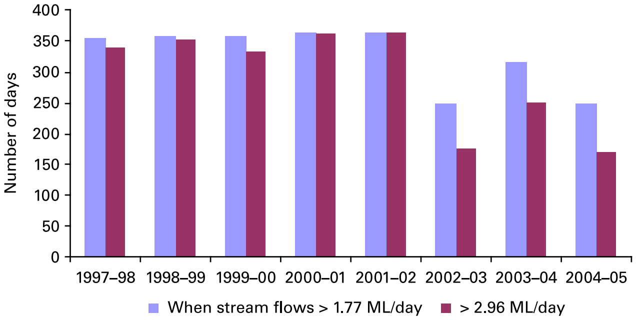

Figure 5 | Number of days during July 1997 to June 2005 when daily stream flows were greater than 1.77 and 2.96 ML/d in the Box Creek SEC.

ECONOMICS OF SALINITY MANAGEMENT OPTIONS

Economic appraisal is a process of comparing the potential costs of each option with the potential benefits that are likely to be realised (Pandey & Rajatasereekul 1999; Marshal & Brennan 2003). In this study, an on-farm economic appraisal model, SWAGMAN Farm (Khan *et al.* 2007*b*), was employed to evaluate the commercial and economic performance of the two identified on-farm salinity management options. Realistic costs and market prices, for the year 2000–01 with 7% discount rate over 30 years of time horizon, were used as inputs to this model. However, in the absence of any market information, opportunity cost and shadow prices were used.

In this model, the selection of crops suitable for the different stages of the SBC system was made taking into account the salinity of the irrigation water, the salinity threshold levels of crops and soil types (Rhoades *et al.* 1992). The relationship between crop salinity threshold and yield reduction from increased soil salinity was adopted from Hanson *et al.* (1993). The salinity levels of the 330 ML off-stream storage was taken equal to 1.5, 2.5 and 3.5 dS/m. The initial soil salinity (EC_e) was assumed to be 0.8 dS/m. The percentage of water use by summer and winter crops was considered equal to 80% and 20%, respectively. The total crop water requirement for each stage (ML) was calculated by multiplying the area under each crop and the crop water requirement.

Cost estimates for evaporation ponds and SBC system

The capital costs of the evaporation ponds include construction of four stages comprising 22 ha of evaporation ponds, cost of pumping from the Box Creek SEC, cost of pipelines, three-phase power connection, earthworks contracting time and exploratory drilling. The total estimated capital cost of four stages comprising 22 ha of evaporation pond(s) is about $170,503, with 10% contingencies allowed. The total cost/ha is about $7,750, which is the similar range as estimated by Singh *et al.* (2000) and Singh & Christen (2000). The overhead and variable costs included pumping, repair and maintenance of bank and ponds, spraying, and insurance costs. The annual estimated overhead and variable cost for an evaporation pond is about $1,135/ha.

The capital costs of four stages of the SBC system are divided into: (i) external infrastructure costs, (ii) land/machinery and site preparation costs, (iii) irrigation infrastructure costs, (iv) environmental approval/monitory costs and (v) contingencies. The total estimated external infrastructure cost is about $217,086. This includes the opportunity cost of land, construction of storage, geotechnical investigation, fencing, electricity connection and miscellaneous costs, which include diversion works and fencing. The land and machinery required to develop land suitable for farming under each stage and for evaporation pond construction is taken into account. The total land purchase for crops, machinery and site preparation is about $60,150. Investments are needed to prepare land so that it is suitable for growing different crops. The total investment on earthworks and irrigation infrastructure cost is about $284,024. Environmental monitoring is necessary to monitor and assess the status and trends of the SBC system on salinity control, and its effect on the local environment. The total environmental approval and monitoring costs are about $2,368. The total capital cost was assumed to be incurred in the first year. The total estimated capital cost is about $591,809 with 10% contingencies allowed. The total cost/ha was about $9,863 which also includes the cost of storage.

There are a number of overhead and variable costs associated with the operation and management of the whole SBC system. These costs include: (i) overheads such as environmental monitoring costs, labour for management and cropping, vehicle registration and running expenses, etc., (ii) operation costs such as pumping cost at each stage, operating cost for evaporation ponds, etc., (iii) maintenance costs such as maintaining storage and channels, land forming and drainage, machinery and pumps, etc., and (iv) irrigation water costs if excess water is required. The total estimated overhead and variable cost is about $12,077 per annum.

Benefit estimates for evaporation ponds and SBC system

The benefit estimates were made, with and without third party impacts, of using the identified on-farm options for managing stream salinity in irrigation areas. For assessing the third party impacts, the concept of willingness to pay (WTP) from a third party was used in the analysis. A similar concept has already been used by the Murray–Darling Basin Commission (MDBC 1996) to define a salinity credit in terms of cost-sharing for any on-ground work. MDBC (1996) defined a value of $49/t/yr as a WTP from a third party to manage stream salinity in the MDB.

Although the value of salt production, both from evaporation ponds and the SBC system, can be estimated by multiplying the total salt produced with the farm gate price of raw salts, the value of salt production is not used to estimate benefits in the economic analysis. Thus, in the case of evaporation ponds, benefit estimates were made without third party impacts. Keeping in view the climatic conditions during July 1997 to June 2005 in the study area, evaporation ponds could potentially remove 781 t/yr on average from the Box Creek. Therefore, using a value of $49/t/yr as a WTO from a third party (after MDBC 1996), the benefits of evaporation ponds with third party impact were estimated to be $38,269.

In the case of the SBC system, benefit estimates were made with and without third party impacts. Without third party impact, the main benefit of the SBC system is the income from saline agriculture. The value of crop production is measured by multiplying the total production by the price. The cropping benefits were determined using SWAGMAN Farm (Khan *et al.* 2007*b*) which determines an optimum crop mix for each stage of the SBC system while maximising the total gross margins subject to water, salinity, land and crop rotation constraints. The total gross margins obtained from the total water use (of different salinity levels) against the optimal crop area used under each stage are given in Table 2. The SWAGMAN Farm model results show that gross margin can be maximised by growing Lucerne in Stages 1 and 2, while growing saltbushes in Stage 3 for different initial salinity levels. The total gross margins ($64,251) at Stage 1 EC (1.5 dS/m) are higher as compared to total gross margins ($55,345) at Stage 1 EC (2.5 dS/m) and ($46,151) at Stage 1 EC (3.5 dS/m), which is due to declining yield at higher salinity levels.

Table 2 | Total gross margins obtained from the total water use (of different salinity levels) against the optimal crop area used under each stage of the SBC system

	Lucerne		Saltbushes		Fallow		
Stages	**Water use (ML)**	**Area (ha)**	**Water use (ML)**	**Area (ha)**	**Water use (ML)**	**Area (ha)**	**Gross margin ($)**
EC (1.5 dS/m)							
Stage 1	323	27	0	0	0	3	50,973
Stage 2	107	9	0	0	0	1	12,528
Stage 3	0	0	36	3	0	1	750
EC (2.5 dS/m)							
Stage 1	323	27	0	0	0	3	46,661
Stage 2	107	9	0	0	0	1	7,934
Stage 3	0	0	36	3	0	1	750
EC (3.5 dS/m)							
Stage 1	323	27	0	0	0	3	41,918
Stage 2	107	9	0	0	0	1	3,483
Stage 3	0	0	36	3	0	1	750

For a given salinity of irrigation water, the root zone salinity depends mainly on the leaching fraction higher leaching fraction would result in less root zone salinity. If root zone salinity exceeds the crop salinity threshold, the crop yield decreases, resulting in reduced crop gross margins. However, in the economic analysis of the SBC system, leaching fraction was taken equal to 33.3% (after Su *et al.* 2005). Therefore, to reflect different field conditions, in terms of plausible leaching fractions, sensitivity of gross margins and leaching fractions was carried out under different salinity levels of off-stream storage to be used for irrigating the SBC system (Figure 6). For leaching fractions higher than 33.3%, the rate of increase in gross margin per unit increase in leaching fraction remains the same for different salinity levels of irrigation water (i.e. EC 1.5, 2.5 and 3.5 dS/m). This rate applies to leaching fractions lower than 33.3% as well, but it is only true for irrigation water of EC 1.5 dS/m. In the case of irrigation water with EC 3.5 dS/m, the gross margin does not change significantly for leaching fractions lower than 33.3%.

Keeping in view the agro-climatic conditions during July 1997 to June 2005 in the study area, the SBC system could potentially help remove 513 t/yr on average during July 1997 to June 2005 from the Box Creek. Therefore, using a value of $49/t/yr as a WTP from a third party (after MDBC 1996), the benefits of the SBC system with third party impact were estimated as $25,137.

Viability of salinity management options

Three main criteria, i.e. (i) Net Present Value (NPV), (ii) Cost Benefit Ratio (CBR) and (iii) Internal Rate of Return (IRR), were use to evaluate the viability of salinity management options. In addition, payback period, i.e. how many years it would take to recover the capital investment, was determined while evaluating the economics of salinity management options. A sensitivity analysis was also carried out to test: (i) the sensitivity of payback period and WTP from a third party (in terms of $/t/yr) for removing the salts (t/yr) and (ii) the sensitivity of payback period and WTP from a third party (in terms of $/ML/yr) for treating the saline water (ML/yr) using the SBC system.

The net present value (NPV), which is a standard method for the economic appraisal of long-term projects, measures the excess or shortfall of cash flows, in present value (PV) terms, once financing charges are met. For its mathematical expression, each cash inflow/outflow is discounted back to its present value, and are then summed (Equation (1)):

$$\mathrm{NPV} = \sum_{t=1}^{n} \frac{C_t}{(1+r)^t} - C_0 \qquad (1)$$

where t is the time of the cash flow, n is the total time of the project, r is the discount rate, C_t is the net cash flow (the amount of cash) at time t and C_0 is the capital investments

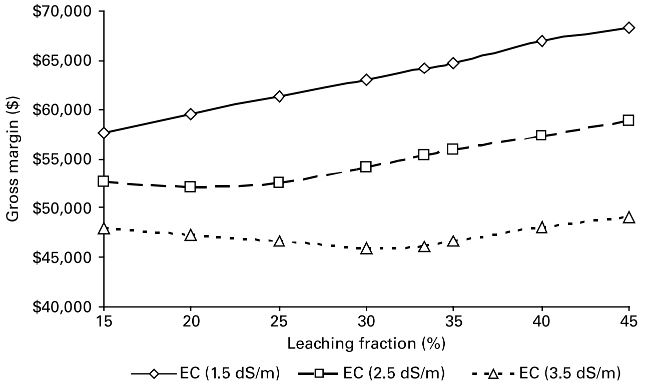

Figure 6 | Sensitivity of gross margins and leaching fractions under different salinity levels of off-stream storage to be used for irrigating the SBC system.

at the beginning of the investment time ($t = 0$). For NPV, a positive value indicates that the project is economically feasible.

A Benefit–Cost Ratio (BCR) is an indicator, used in the formal discipline of cost–benefit analysis, which attempts to summarise the overall value for money of a project. A BCR is the ratio of the benefits of a project, expressed in monetary terms, relative to its costs, also expressed in monetary terms. Its value over 1 indicates the economic desirability of the project. All benefits and costs should be expressed in discounted present values. In practice, the ratio of NPV to expenditure is expressed as a BCR.

The Internal Rate of Return (IRR) is a capital budgeting method used to decide whether they should make long-term investments. The IRR takes into account the time value of money by considering the cash flows over the lifetime of a project. Cash flow is the measure of the actual cash generated by a project or the amount of cash earned after paying all expenses and taxes. Mathematically, the IRR is defined as the discount rate that makes the project have a zero NPV of a series of cash flows. An IRR above the prevailing discount rate shows that the project will generate economic benefits.

The IRR uses the NPV equation as its starting point (Equation (2)):

$$\mathrm{NPV} = 0 = C_0 + \frac{\text{First Year Cash Flow}}{(1+\mathrm{IRR})^1} + \dots + \frac{\text{Last Year Cash Flow}}{(1+\mathrm{IRR})^n} \qquad (2)$$

where n is the last year of the lifetime of the project and calculating the IRR is done through a trial-and-error process that looks for the discount rate that yields an NPV equal to 0. The IRR is therefore the maximum allowable discount rate that would yield a value considering the cost of capital and risk of the project. For this reason,

Table 3 | Economic viability of evaporation ponds and the SBC system, estimated with and without third party impacts, to manage stream salinity

	Net present value (NPV)	Benefit cost ratio (BCR)	Internal rate of return (IRR)	Payback period (years)
Evaporation ponds				
With third party impact - $49/tonne/year as a "willingness to pay" (MDBC 1996)				
EC (1.5 dS/m)	−$273,667	0.42	–	>30
EC (2.5 dS/m)	−$142,628	0.70	–	>30
EC (3.5 dS/m)	−$11,588	0.98	6.19%	>30
SBC system				
Without third party impact				
EC (1.5 dS/m)	$94,314	1.13	8.73%	21.47
EC (2.5 dS/m)	$5,160	1.01	7.10%	29.68
EC (3.5 dS/m)	−$88,337	0.88	5.24%	>30
With third party impact - $49/tonne/year as a "willingness to pay" (MDBC 1996)				
EC (1.5 dS/m)	$299,063	1.59	12.46%	12.73
EC (2.5 dS/m)	$345,043	1.94	13.52%	11.48
EC (3.5 dS/m)	$386,681	2.66	14.57%	10.35

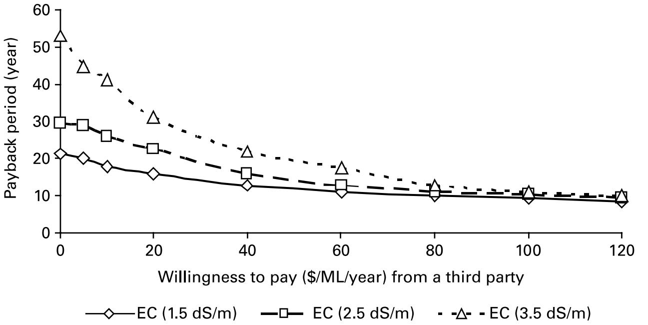

Figure 7 | Sensitivity of payback period and willingness to pay (in terms of $/ML/yr) for treating the saline water (ML/yr) using the SBC system.

the IRR is sometimes referred to as a break-even rate of return. It is the rate at which the value of cash outflow equals the value of cash inflow.

The economic evaluation indices indicate that investing in the SBC system is an economically viable option, both with and without third party impact, which is evident from the IRR, which is greater than the specified discount rate (7%), positive NPV and BCR greater than 1 (Table 3). However, in one instance without third party impact under salinity level at Stage 1 EC (3.5 dS/m), the SBC system was found uneconomical. This was due to a higher level of salinity significantly reducing crop yield, thus affecting the gross margins and economics.

On the other hand, the evaporation pond(s) was not an economically feasible option under different levels of initial salinity. The NPV of evaporation pond(s) was negative even with third party impact. Also, the BCR was less than 1 in both cases. For evaporation ponds, the estimated break-even salt production was about 760 t/yr. The payback period reduces to ten years at a WTP of $155, $95 and $65/t/yr, respectively, for managing stream flows of 1.5, 2.5 and 3.5 dS/m salinity levels using evaporation ponds.

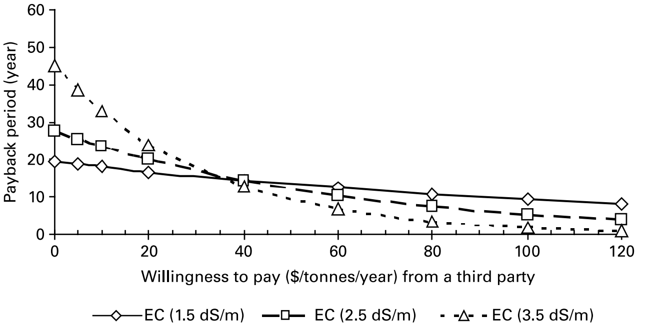

Figure 8 | Sensitivity of payback period and willingness to pay (in terms of $/t/yr) for removing the salts (t/yr) using the SBC system.

In the Box Creek SEC, stream salinity and stream flow vary considerably over a period of time. For productive use of the SBC system, the availability of stream flows, as compared to reliable stream salinity, is of prime importance. Therefore, it may be appropriate to define a value of WTP, in terms of $/ML/yr, from a third party. Figure 7 shows the sensitivity of the payback period and WTP from a third party (in terms of $/ML/yr) for treating the saline water (ML/yr) using the SBC system. Without third party impact, the payback period is about 20.2 years. With third party impact, the payback period varies depending upon the salinity (i.e. 1.5, 2.5 or 3.5 dS/m) of 330 ML off-stream storage made available for irrigation use in the SBC system. A payback period of 12.55 years can be achieved with a WTP of $40, $60 and $80/ML/yr, respectively, for irrigation water with a salinity of 1.5, 2.5 and 3.5 dS/m. However, the payback period reduces to ten years at a WTP of $100/ML/yr from a third party, provided the salinity of irrigation water remained between 1.5 and 3.5 dS/m.

However, to internalise the concept of WTP, in terms of cost-sharing for any on-ground work in managing stream salinity in the MDB, it is important to define the value of WTP, in terms of $/t/yr, from a third party. Figure 8 shows the sensitivity of the payback period and WTP from a third party (in terms of $/t/yr) for removing the salts (t/yr) using the SBC system. The payback period becomes 15 years with a WTP of $35/t/yr from a third party, irrespective of the salinity level of the irrigation water. Therefore, for a WTP higher than $35/t/yr from a third party, the payback will be less for irrigation water with higher salinity as compared with lower salinity. For instance, with a WTP of $100/t/yr from a third party, the payback period becomes 9.3, 5.5 and 1.9 years, respectively, for irrigation water with a salinity of 1.5, 2.5 and 3.5 dS/m. Thus, at a higher WTP (in term of $/t/yr) from a third party, it is actually more economical to irrigate with irrigation water with higher salinity.

CONCLUSIONS AND RECOMMENDATIONS

Increasing salt concentration in tributaries is the prime contributor to environmental degradation of rivers, creeks, streams or other water bodies. In the case of the Box Creek

SEC, although the contribution of flows was fairly low (approximately 7%) relative to the total flows leaving the Murray Irrigation, these flows contribute significantly (approximately 45%) to the salt concentration that leaves the Murray Irrigation. Therefore, salinity management of the Box Creek SEC flows would have significant impact on achieving salinity credits for the Murray Irrigation.

For separating highly saline water from the Box Creek SEC, direct pumping was considered appropriate compared to either shallow tubewell installation, subsurface interceptor drainage, open channel partitioning and weir construction. For making productive use of pumped water, two salinity management options were considered at a suitable community farm location: (i) evaporation ponds for harvesting salts as a marketable product and (ii) an SBC system as an option for saline agriculture.

The economic evaluation indices indicate that investing in the SBC system is an economically viable option, both with and without third party impacts. However, without third party impact, the payback period of the SBC system is over twenty years. On the other hand, the evaporation pond(s) is not an economically feasible option. The NPV of evaporation pond(s) is negative with and without third party impacts. Also, the BCR is less than 1 in both cases. The sensitivity analysis indicated that the payback period reduces to ten years at a WTP of \$100/ML/yr from a third party, provided the salinity of irrigation water remained between 1.5 and 3.5 dS/m. On the other hand, with a WTP of \$100/t/yr from a third party, the payback period becomes 9.3, 5.5 and 1.9 years, respectively, for irrigation water with a salinity of 1.5, 2.5 and 3.5 dS/m. Thus, at a higher WTP (in term of \$/t/yr) from a third party, it is actually more economical to irrigate with irrigation water with higher salinity. As the values of WTP (either in terms of \$/ML/yr or \$/t/yr) from a third party critically affect the economic justification for the investments in stream salinity management, there is a need to further investigate the plausible range of these values.

The use of a target salinity level of 800 EC (μS/cm) in the lower reaches of the Murray River for managing the entire Murray–Darling Basin is not appropriate as a management tool. It serves only as a 'warm fuzzy' benchmark but fails to translate into on-farm actions which can be taken if this threshold is exceeded. We present this paper from the standpoint of believing that the polluter should pay and hence logically take the responsibility back to the farm level in our example, but the argument could equally apply to a municipality, a natural saline stream discharge, an individual industry or a factory. Only by an accumulation of these 'point sources' management strategies can the 800 EC target in the lower reaches of the Murray River (i.e. at Morgan) be meaningful and enforceable.

The SBC system for managing saline stream flow may be applicable across a wide spectrum of activity we believe an investigation of the economic and hydrological feasibility of this approach should be mandatory in developing stream salinity management options. The adoption and success of the SBC system would not only help in seasonal management of flows and vegetation, but also improve the overall surface water quality and agricultural production in the Box Creek catchment. The feasibility of salinity management for the Box Creek SEC will help in achieving the salinity credits for the Murray Irrigation, as well as enable salinity credits for the Murray River.

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