Offsetting with salinity credits: An alternative to irrigation zoning

Thomas Spencer and Tihomir Ancev

Agricultural and Resource Economics (A04), University of Sydney,
Sydney, NSW, 2006 Australia

Contact author is Ancev (t.ancev@usyd.edu.au)

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Abstract

Irrigation induced salinity is a serious problem in many countries around the world. In Australia, this type of salinity is most pronounced in the valley of the River Murray in South Australia. Location of irrigation enterprises has been identified as a key factor that needs to be taken into account by policies aimed at mitigating salinity. This article compares and contrasts two such policies: an irrigation zoning policy, where new irrigation enterprises are only allowed in low salinity impact zones, and an offsetting with salinity credits policy, where new irrigation enterprises can locate in high salinity impact zones, provided they offset their salinity impact with salinity credits. Key findings are that the offsetting policy will be both less costly and more effective in reducing salinity than a standalone irrigation zoning policy. This is due to the presence of incentives for choosing "optimal" location of irrigation enterprises when costs of salinity credits are taken into account.

Key words: irrigation, least-cost, offsets, salinity

JEL Codes: Q15, Q18, Q25, Q50.

Introduction

Irrigation induced salinity has been an inadvertent follower and the ultimate doom of many prosperous agricultural systems throughout history. In Australia, irrigation induced salinity was identified as a serious problem since the early stages of irrigation development (Quiggin, 1988). This problem is most pronounced in the valley of River Murray in South Australia (ibid). Various technical solutions have been devised to control irrigation induced salinity, including dilution flows, salinity interception schemes etc. (Heaney et al. 2001, Connor, 2004). The importance of spatial location of irrigation enterprises has also been noted and policies have been devised that mandate or provide incentives for irrigation developments to locate in areas where they would cause less salinity impact (Gordon et al., 2005; Duke, 2004). Most recently, an irrigation zoning policy has been implemented that restricts the location of new irrigation development to areas where salinity impact is relatively low. New irrigation developments in high salinity impact areas are prohibited. This zoning policy is likely to reduce the salinity impact but it will also increase aggregate irrigation costs for the region. Since typically the low salinity impact zones are located further away from the river channel, zoning will increase aggregate costs of irrigation as a result of higher water delivery costs due to increased costs of piping and pumping water.

An alternative to this standalone zoning policy would be to implement an offsetting scheme, whereby the salinity impact from new irrigation development in the high salinity impact zones will be offset by reduction of salinity impact elsewhere. This gives rise to salinity credits. Trading in salinity credits will reduce the salt impact, while reducing the overall costs of compliance to the irrigation industry.

The primary objective of this paper is to determine whether implementing an offsetting system of tradeable salinity credits in the South Australian Riverland can reduce the costs of achieving long term salinity impact reductions as projected under the standalone irrigation zoning policy. This is done by comparing the costs of both standalone irrigation zoning policy and the offsetting policy. Since the relative spatial location of irrigation enterprises along the river channel has significant meaning— upstream irrigation has greater salinity impact than the downstream irrigation— an additional objective is to determine the effect of the salinity offset scheme on the spatial location of new irrigation developments.

This study builds on prolific literature on environmental offsetting using credits for non-point source pollution (e.g Shortle and Horan, 2001; Randall and Taylor, 2000; and Stavins, 2000). The problem of irrigation induced salinity in Australia has also been widely explored from an economic perspective (Quiggin, 1988 and 2001, Heanney et al. 2001). Alternative policies to address irrigation induced salinity with a particular focus on the River Murray and South Australia have been recently analysed by Connor et al. (2004) and Connor (2004). The present paper goes beyond these studies to formulate a theoretical framework for salinity credit offsetting scheme and to empirically test the derived theoretical results.

Theory

Let us consider a region surrounding a river which can be delineated into a number of analysis areas. Each of these areas has a high and low salinity impact zone defined within its realms. Classification of high and low impact zones is based on the potential to contribute to long term river salinity through salt load from these zones. Within each zone there is current irrigation activity, and also new irrigation activity can potentially be developed.

The cost of water delivery is assumed to differ across analysis areas and between salinity impact zones. Irrigators located further from or higher above the river channel (i.e. in low impact zones) face higher water delivery costs resulting from higher fixed costs (piping) and higher operation costs (pumping) . Salinity impact resulting from an irrigation development is assumed to be higher if the development is located further upstream, as it impacts greater number of downstream water users.

Unregulated irrigation development

To establish a baseline, consider a situation where the location of new irrigation developments is not restricted. In the absence of regulation, the problem from irrigation industry's perspective is to maximise overall profits, Π, by choosing where to locate new irrigation developments:

$$\max_{H_{a,z}} \quad \Pi = \sum_{a \in A} \sum_{z \in Z} \left[\left(\sum_{c \in C} (d_{a,c}(p_c y_c - OC_c)) - WSC_{a,z} \right) \times H_{a,z} \right]. \qquad (1)$$

$$a \in A = \{1,...,n\},\ z \in Z = \{H, L\},\ c \in C = \{1,...,m\}$$

The choice variable, $H_{a,z}$ represents the number of hectares of new irrigation development that are established in analysis area *a* and impact zone *z*. The set *A* contains the analysis areas, and is so ordered that a lower number indicates that the analysis area is located further downstream. *Z* represents the set of impact zones, and *C* represents the set of possible crop types. p_c is the price of crop *c*; y_c represents the yield of crop *c; OC_c* represents the costs of irrigated production for crop *c* excluding the cost of water delivery and application; $WSC_{a,z}$ represents the average water delivery and application cost for area *a* and salinity impact zone *z*; and $d_{a,c}$ represents the proportion of crop *c* that is currently produced in *a*, where $0 \le d_{a,c} \le 1$ and $\sum_{c \in C} d_{a,c} = 1$.

The problem stated above is constrained by the maximum number of hectares on which new irrigation development can take place each year in the whole region and by the maximum number of hectares of new irrigation development in the individual analysis areas and zones. In the ensuing empirical study these constraints were based on water availability projections and long term observed trends.

Maximizing the objective function in Eq. (1) subject to the stated constraints would result in a solution that reflects the tendency to locate as close as possible to the river channel, driven by the difference in water delivery cost. This is consistent with reality, as a major proportion of irrigation is located within the high salinity impact zones of the South Australian Riverland (21,500 ha. in high impact zones and 9,400 ha in low impact zones).

Irrigation zoning

The introduction of a zoning policy prevents new irrigation development from locating in high impact zones, which effectively adds an additional constraint to the problem presented in Eq. (1). Under this policy, all new irrigation has to locate in the low impact zones and hence the overall regional profits are:

$$\Pi^{Z} = \sum_{a \in A} \Pi_{a}^{Z} = \sum_{a \in A} \left[\left(\sum_{c \in C} \left(d_{a,c} \left(p_{c} y_{c} - OC_{c} \right) \right) - WSC_{a,z=L} \right) \times H_{a,z=L} \right] \tag{2}$$

where Π_{a}^{Z} denotes profits in any analysis area *a* under the zoning policy.

Offsets using salinity credits

Under an offsetting system, irrigation can take place in both low and high salinity impact zones. From the irrigation industry's perspective the problem may be formulated as:

$$\max_{H_{a,z}} \quad \Pi^{T} = \sum_{a \in A} \left[\left(\sum_{c \in C} \left(d_{a,c} \left(p_{c} y_{c} - OC_{c} \right) \right) - WSC_{a,z=L} \right) \times H_{a,z=L} \right] \tag{3}$$

$$+ \sum_{a \in A} \left[\left(\sum_{c \in C} \left(d_{a,c} \left(p_{c} y_{c} - OC_{c} \right) \right) - WSC_{a,z=H} - p_{credit} . S_{a,z=H} \right) \times H_{a,z=H} \right]$$

where p_{credit} is the price of a salinity credit, and $S_{a,z=H}$ represents the salinity impact per hectare of irrigation located within the high salinity impact zone of analysis area *a*.

For simplicity, and in order to match annual demand with the annual supply of credits rather than having to match demand and supply of salinity credits over the lifetime of an irrigation development, we assume that salinity credits are leased out on an annual basis. The suppliers of credits are existing irrigation enterprises located in the high impact zones that could redevelop through a normal replacement of portions of their crop enterprises that have come to the end of their productive life. They can proceed with this replacement and thus continue to have a negative salinity impact, or they can choose not to replace and hence obtain salinity reduction credits. They can then sell these credits to the developers who would like to develop new irrigation enterprises in any high salinity impact zone.

Demand for salinity credits

Differentiating Eq. (3) with respect to $H_{a,z}$ yields:

$$\frac{\partial \Pi^T}{\partial H_{a,z=L}} = \sum_{c \in C} (d_{a,c}(p_c y_c - OC_c)) - WSC_{a,z=L} \qquad (4)$$

$$\frac{\partial \Pi^T}{\partial H_{a,z=H}} = \sum_{c \in C} (d_{a,c}(p_c y_c - OC_c)) - WSC_{a,z=H} - p_{credit} S_a \quad . \qquad (5)$$

Equating (4) and (5) and solving simultaneously gives:

$$p^*_{a,credit} = \frac{WSC_{a,z=L} - WSC_{a,z=H}}{S_a} \qquad (6)$$

where $p^*_{a,credit}$ represents the maximum amount that a developer would be willing to pay for salinity credits in analysis area *a.* For any credit price less than this maximum amount, $p_{credit} < p^*_{a,credit}$, a developer of a new irrigation will choose to buy the offset credit and to locate within the high impact zone of a . This will yield them:

$$\Pi^T_{a,z=H} = (\sum_{c \in C} (d_{a,c}(p_c y_c - OC_c)) - WSC_{a,z=H} - p_{credit}.S_{a,z=H,y}) \times H_{a,z=H} > \Pi^Z_a \quad , \qquad (7)$$

where $\Pi^T_{a,z=H}$ is the profit under the salinity offsetting scheme (superscript ^{T}) in area *a*, and Π^Z_a is the profit under the standalone zoning policy (superscript ^{Z}) in the same area. When the credit price is equal to the maximum amount, $p_{credit} = p^*_{a,credit}$, a developer of new irrigation will be indifferent between locating in the high or the low impact zone. If the credit price is greater than the maximum amount the developer is willing to pay for credits in *a,* $p_{credit} > p^*_{a,credit}$, then new irrigation will locate in the low salinity impact zone, and obtain a profit equivalent as under the standalone zoning policy. This enables us to state the following result:

Result 1*:* Under an offsetting system with tradeable salinity credits, assuming negligible transaction costs, the profits obtained from a new irrigation development in each analysis area are at least as large as those obtained under irrigation zoning.

This is seen by:

$$\Pi_a^T = \begin{cases} \Pi_{a,z=H}^T > \Pi_a^Z & if\ \ p_{credit} < p_{a,credit}^* \\ \Pi_a^T = \Pi_a^Z & if\ \ p_{credit} = p_{a,credit}^* \\ \Pi_{a,z=L}^T = \Pi_a^Z & if\ \ p_{credit} > p_{a,credit}^* \end{cases} \quad . \tag{8}$$

We can proceed by looking at the demand for salinity reduction credits in area a, Q_a^d :

$$Q_a^d = \begin{cases} S_a \cdot H_{a,z=H} & if\ \ p_{credit} < p_{a,credit}^* \\ [0,\ S_a \cdot H_{a,z=H}] & if\ \ p_{credit} = p_{a,credit}^* \\ 0 & if\ \ p_{credit} > p_{a,credit}^* \end{cases} \tag{9}$$

Salinity impact resulting from new irrigation development is assumed to be higher for areas located upstream, that is: $S_1 \leq S_2 \leq \cdots \leq S_n$. This is because the salt load from irrigators further upstream affects relatively more downstream users (irrigators, municipalities, industries), as compared to the loads coming from downstream irrigators. Assuming that the difference in water delivery costs between the high and low impact zones across all areas is the same, we can infer that the maximum amount developers are willing to pay for salinity credits will be higher for areas further downstream, than for the upstream areas, $p^*_{1,credit} \geq p^*_{2,credit} \geq \ldots \geq p^*_{n,credit}$. This enables us to state the following result:

Result 2: When the distribution of crop types in each area along the river is constant, that is $d_{a,c} = d_c \quad \forall a \in A$ and $\forall c \in C$, and the difference in water delivery costs between the high and low impact zones is the same across areas, salinity credits will be demanded by all downstream areas, $a \in \{1, \cdots, j\} \subset A$, for which the credit price is lower than the maximum amount that developers are willing to pay for salinity credits in those areas, $p^*_{j,credit} > p_{credit} \geq p^*_{j+1,credit}$.

Supply of salinity credits

Every year, a certain portion of the irrigated land within the high impact zone is due for redevelopment because it has come to the end of its productive life. In the presence of an offsetting scheme with salinity credits, the irrigators can choose whether to replant or to supply credits. If the irrigators choose to replant they obtain the profit from redevelopment $(\sum_{c \in C} (d_{a,c}(p_c y_c - OC_c)) - WSC_{a,z=H}) \cdot H_{a,z=H,red}$. If the area is not replanted, irrigators are entitled to salinity credits, which they can sell and obtain a payoff of $S_a \cdot H_{a,z=H,red} p_{credit}$. Following a similar procedure as in the analysis of the demand, we are able to derive:

$$p^{**}_{a,credit} = \frac{\sum_{c \in C} (d_{a,c}(p_c y_c - OC_c)) - WSC_{a,z=H}}{S_a} \quad , \qquad (10)$$

where $p^{**}_{a,credit}$ represents the 'threshold supply price' for salinity credits, above which no irrigation is redeveloped in *a,* and the maximum number of salinity credits are supplied; and below which all land in *a* is redeveloped and no credits are supplied. This enables us to formulate a supply function for salinity credits:

$$Q_a^s = \begin{cases} 0 & if \;\; p_{credit} < p^{**}_{a,credit} \\ [0,\, S_a \cdot H_{a,z=H,red}] & if \;\; p_{credit} = p^{**}_{a,credit} \\ S_a \cdot H_{a,z=H,red} & if \;\; p_{credit} > p^{**}_{a,credit} \end{cases} \qquad (14)$$

Similarly to the demand for salinity credits, the higher the salinity impact resulting from irrigation development in an area, the lower the 'threshold supply price' above which salinity credits will be supplied to the market. Since the salinity impact is greater for areas located upstream, and assuming that the distribution of crop types across areas is constant, we can infer that the 'threshold supply price', above which credits are supplied, will be lower for upstream areas: $p^{**}_{1,credit} \geq p^{**}_{2,credit} \geq \ldots \geq p^{**}_{n,credit}$. This leads to the following result:

Result 3: When the distribution of crops across areas along the river is constant, $d_{a,c} = d_c \;\; \forall a \in A$ and $\forall c \in C$, and when water delivery costs in the high impact zone across areas are the same, salinity credits will be supplied by the k upstream areas, $a \in \{n-k+1, \cdots, n\} \subset A$ for which the credit price is higher than the 'threshold supply price, $p^{**}_{n-k,credit} \geq p_{credit} \geq p^{**}_{n-k+1,credit}$.

Methods and data

The South Australian Riverland has been delineated into seventeen Land and Water Management Plan (LWMP) areas for the purposes of this analysis. This is presented in Figure 1. Each area is classified into a high impact zone ($z = H$) and a low impact zone ($z = L$), except two— Monash only has a low impact zone and Gurra Gurra Lakes only has a high impact zone.

Irrigated agriculture in the region is composed of five major crops: almonds, grapes, oranges, apricots, and potatoes. In 2005 these crops represented 85% of total irrigated agriculture in the region by acreage. Yields, prices, fixed and variable costs for these crops were obtained from LMLF (2005). Average crop water requirement and the costs of both existing and new water licences were obtained from the same source. The impact of river water salinity on crop yields was obtained from Lantzke and Calder, 2005. Water delivery costs were calculated based on average distances and elevation of various analysis areas, costs of piping and electricity costs. The salt load and the salinity impact from each of the areas under a given distribution of crops were obtained from CSIRO PERU (2002).

Based on this data, profits and salinity loads were calculated for each crop in each zone of each analysis area. These were then fed into a linear programming model that was run under three scenarios: a baseline scenario, where no restriction on new irrigation development has been imposed; an irrigation zoning scenario, where new irrigation could only take place in low salinity impact zones; and a salinity credit offset scenario, where irrigation can locate in high salinity impact zones provided the salinity impact is offset.

For each scenario, the objective functions corresponding to equations 1, 2 and 3 were maximised subject to the appropriate set of constraints as discussed in the theory section. The demand and supply functions for salinity credits were parameterized by varying the price of salinity credits and repeatedly resolving the program for each parameterized value.

Results

Under the baseline scenario, most new irrigation development located in the high impact zones. The overall annual profit from irrigation activities for the whole region under this scenario was AUD 3,665,231. The salinity impact under this scenario was calculated to be 4236 EC units over the next 100 years. Even though this might be a considerable overestimate because of the "representative" nature of the salinity impact across areas, an overall salinity impact under this scenario will be substantial under any circumstances.

Under the standalone irrigation zoning scenario all new irrigation had to locate in the low impact zones. The overall annual profit from irrigation activities for the whole region under this scenario was AUD 3,183,113. The salinity impact under this scenario was calculated at 338 EC units 100 years after development, which is considerably lower compared to the baseline scenario.

Under the offsetting with salinity credits scenario, new irrigation can be located both in low and high salinity impact zones, provided that the salinity impact from new developments in high impact zones are offset with salinity credits. The overall annual profit for the whole region under this scenario was AUD 3,290,627. Net salinity impact under this scenario was calculated at 288 EC units, 100 years after development. The equilibrium quantity of salinity credits was 144 EC units, with an associated equilibrium price of AUD 606 per EC unit. A trend of locating in both high and low salinity impact zones but somewhat downstream, as compared to the previous two scenarios was observed. In essence, the developer would choose to locate further downstream whenever the reduction in profits, as a result of the impact of higher irrigation water salt concentration on yield, are less than the costs of buying additional salinity offset credits to locate upstream. This trend of locating downstream is responsible for the result of obtaining lower net salinity impact under offsets as compared to the salinity impact under standalone irrigation zoning. Results for all scenarios are summarised in Table 1.

Discussion

Results obtained from simulating the three scenarios indicate several important findings. One is that the location of irrigation enterprises has to be addressed in some way in order to prevent excessive salt load into the River Murray. A regime of unrestricted irrigation development will result in extremely high salinity impact. The economic benefits from such *laissez-faire* policy are not significant as compared to the other policies considered. A standalone policy that will rigidly restrict the location of new irrigation developments will result in significant reduction of the salinity impact. However, the cost of this policy will be higher than the cost of alternative policy that allows offsetting of salinity impacts.

An offsetting policy with salinity credits achieves a significant reduction of the overall salinity impact level, and at lower cost. While costs savings relative to a standalone zoning policy are not enormous (about AUD 110,000 per anum), the reduction of salinity impact of the offset policy is in fact superior compared to the standalone zoning policy. This is a result of greater flexibility in location choices. Given the substantial costs of salinity credits, new irrigation developments will tend to locate in the areas where relatively fewer credits will be required. This tendency results in a lower net salinity impact under the offset policy.

Summary and conclusion

The paper addresses the problem of choosing policies for mitigating irrigation induced salinity at least-cost. Since the spatial location of irrigation enterprises plays a key role in determining the salinity impact of those enterprises, policies that restrict the location choices have been proposed and implemented to address the problem. One such policy is the irrigation zoning, recently adopted in South Australia. The paper compares this to an alternative policy, where the location of new irrigation enterprises is not restricted *per-se*, but any new developments in areas that are designated as “high salinity impact” are required to purchase salinity credits for offsetting.

Key theoretical findings are that offsetting policy will be as profitable as standalone irrigation zoning policy in any analysis area, and that the salinity credits will be demanded by the downstream irrigators and supplied by upstream irrigators. These results were tested in an empirical study. The study simulated three scenarios using linear programming methods: a baseline scenario of unregulated irrigation expansion, an irrigation zoning scenario and an offsetting with salinity credits scenario. The results suggest that both irrigation zoning and offsetting policy will do much better in terms of salinity impact as compared to the baseline scenario, and will do so at very reasonable costs. Direct comparison of the standalone zoning and offsetting scenarios however show that offsetting policy achieves both better salinity outcome and at lower cost than a standalone zoning scenario.

Several conclusions can be drawn from the above discussion. Influencing the location of irrigation enterprises in order to mitigate irrigation induced salinity, either by quantity regulation, as presented here, or by price regulation (Gordon, 2005; Duke, 2004), is a sound policy option. However, a pure quantity regulation in the form of irrigation zoning is going to be more costly and less effective in achieving reduction of salinity impact, as compared to more flexible, incentive based policy. An offset policy using salinity credits is one such policy, and the tests conducted here showed that it is superior to the standalone zoning policy, both in terms of costs and in terms of salinity reduction.

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Table 1. Costs, salinity impact, quantity and price of salinity credits under the three policy scenarios.

	Annual cost (AUD)	Discounted costs over 100 years (mill. AUD)	Net salinity impact (EC increase projected over 100 years)	Number of salinity credits	Price of credits (AUD/ EC unit)
Baseline Scenario: Unrestricted irrigation	0	0	4,263	0	0
Scenario 1: Zoning with no offsets	482,118	7.4	338	0	0
Scenario 2: Salinity offsets	374,604	5.8	288	144	606

Figure 1. Analysis areas in the South Australian Riverland.