Property Rights and Sustainable Land use on a Salinity-affected Catchment*

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Abstract

Dryland salinisation is a non-point and intertemporal stock externality which requires a dynamic modelling approach to study its long-term management. In this paper a simple dynamic optimisation model is developed and applied to find land-use strategies that maximise benefits from the viewpoints of both individual farmers and the catchment as a whole. Privately optimal land-use may result in an ever-increasing trend in salinity and a declining trend in productivity for the discharge zone of the catchment. Considerable welfare losses may occur under private management when the recharge and the discharge zones are owned by different individuals. These welfare losses are estimated by comparing the value of the stream of benefits obtained by the catchment under private management with those obtained when management is under a common property regime. Difficulties in establishing such a system are discussed, in particular the problem of establishing enforceable common property rights over the groundwater table.

Key words: Dryland salinity, dynamic modelling, sustainable land-use, common property

Introduction

Dryland salinity is the presence of an excessive amount of soluble salt in the soil that may affect the growth and productivity of crops and other vegetation. It is an important land degradation issue throughout Australia. The problem is caused by imbalances in groundwater systems due to widespread clearing, which replaced deep-rooted, perennial native vegetation, by shallow-rooted agricultural plants. Dryland salinity may cause irreversible loss of land and productivity. It imposes a range of costs on individual farmers affected by salinity and the whole nation through flow-on costs and changes to the natural environment. It restricts the crop selection that can be produced and reduces crop growth and productivity. The total salt-affected land in Australia was 2,476,000 hectares in 1996 of which 73 per cent was in Western Australia, 16 per cent in South

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Australia, Victoria and New South Wales had 4.8 per cent each, Tasmania had 0.8 per cent and Queensland had 0.4 per cent (Bennet 1998). It was predicted that total potential salt affected land area at equilibrium would be 11,783,000 hectares if the current levels of salinity were not treated. Donaldson Planning and Management Services (1996) reported that the watertable in the Liverpool Plains Catchment was within two metres of the surface for 17,000 hectares and this figure would rise to 50,000 hectares within a few years if immediate preventive action were not taken. A hydrological study in the Liverpool Plains Catchment shows a general trend in rising groundwater levels across the catchment (Zhang et al. 1997).

According to Greiner (1994), the extensive development of soil salinity is threatening the financial and environmental sustainability of a large number of farm businesses. Salinity leads to a decrease in property values. It exacerbates the decline in rural economies and endangers the productive capacity of a major resource in large parts of Australia.

Poulter and Schaffer (1991) emphasised the need for scientific and economic analysis of land-use practices for efficient policy formulation. According to them, economic information on the interaction of farm management practices, land quality and farm profitability needs to be acquired to make economically viable plans from both land-holder and social perspectives.

The presence of externalities in land-use practices is an important cause of market failure associated with dryland salinity in Australia. In the process of making resource-allocation decisions Pareto-optimal[**] resource allocation is violated and sub-optimal resource allocation is achieved if there is an externality. Commonwealth and state government agencies across Australia have devoted considerable funds to combating the impacts of salinity related problems (Robertson 1995, quoted in Oliver et al. 1996). Despite the significant investment in research, development and extension, the extent and severity of salinity related problems have continued to worsen in many areas (Oliver et al. 1996).

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[**] Pareto-optimal resource allocation is a situation or condition where there is no possibility of further reallocating resources to make one person in the economy better off without making someone else worse off.

There are a number of externalities for farms as well as for the region which need to be evaluated and internalised for efficient use of the land resources including maintenance of biodiversity and ecological balance.

The divergence between social and private discount rates is another important issue causing market failure in natural resource management. One of the important concerns in interpreting sustainability of resource use and management is determining the weights for interests of future generations compared with current generations (Quiggin 1993, p.1). The individual landholders use higher discount rates than society, resulting in over-exploitation of resources and land degradation. This is supported by Dalziell and Poulter (1992) and, Mues and Collins (1993), quoted in Wilson (1995, p. 36) which argue that landholders even with perfect information about the consequences of their current land management decisions may produce a level of salinisation higher than is socially desirable because they give more importance to current consumption and hence use a higher discount rate than society in calculating present value of future benefits and costs.

Dryland salinisation is a non-point and intertemporal type of externality, and a dynamic modelling approach is required to capture the intertemporal effects. Biophysical processes in the catchment influence land-use decisions and economic benefits hence economic analysis must consider biophysical processes in the catchment. Individual farmers enjoy private ownership property rights over their land, but they share a common aquifer for accessing the groundwater systems. Therefore, a common-property approach is used in this paper to address the externality problem and determine sets of pareto-optimal land-uses. The economically optimal level of salinisation will also be evaluated.

Objectives of the study

The accurate estimation of recharge into the groundwater system and prediction of the emergence of salinity due to land-use practices are crucial to proper management of dryland salinity. Salinity externalities associated with land-use decisions may cause land to be allocated inefficiently, meaning policies are needed to help achieve maximum benefits for society from land-use. Accordingly, we set the following specific objectives for the study:

1) to develop a model for estimating the land-use mix that maximises benefits from individual and social points of view;

2) to examine the nature and magnitude of welfare losses to society due to the existence of salinity externalities in a catchment; and

3) to suggest a policy framework that can overcome the externality problem and help achieve an optimal level of land-use.

In this paper, a simple dynamic optimisation model is developed and used to achieve the objectives set above. In the model the catchment is divided into recharge and a discharge zones, each represented by a model farm. The final value of land is then estimated in the model. The optimal pattern of land-use and the corresponding level of salinity and benefits to the catchment are estimated. Welfare losses to society due to management decisions by individuals are also assessed.

A simple model

A catchment like the Liverpool Plains comprises recharge and discharge zones with contrasting characteristic features. The recharge zone lies upstream and causes salinity in the discharge zone (downstream) through its land-use practices. The literature suggests that the discharge zone, the Plains containing black soil, is more productive than the recharge zone (Greiner 1997, p. 24). The discharge zone may also incur higher costs of production because of salinity and water logging (Wilson 1995, p. 19). For simplicity, the farm units of the catchment are aggregated into two representative farms: one in the recharge zone and the other in the discharge zone. Two crops are assumed to be grown throughout the catchment: one is more profitable, causes salinity and is sensitive to salinity. The other is less profitable, reduces salinity and is less sensitive to salinity. Yields of crops in the discharge zone are influenced by the salinity status of the land. In the private solution, the effects of land-use practice in the recharge zone and corresponding costs of damage are uncompensated. It is assumed that private individuals are more concerned with present needs and consumption and cannot spread risks over a long planning period in production decisions, and therefore would exhibit higher discount rates than society as a whole.

It is assumed farmers are rational and maximise profits over a given planning horizon. The objective function *(TNPV)* is the flow of net farm income from both zones of the catchment over the planning period. The model can be stated as:

$$\underset{U,V}{Max}\,TNPV = \sum_{t=1}^{T}\left[\pi^{R}\left(U_{t}\right)+\pi^{D}\left(U_{t},V_{t},S_{t}\right)\right]e^{-\alpha t} \qquad \textbf{(1)}$$

where, π^{R} and π^{D} represent the profits derived from the recharge and the discharge zones, respectively. *U* and *V* represent vectors of decision variables; $U=\left[u_1,u_2\right]$ for the recharge zone and $V=\left[v_1,v_2\right]$ for the discharge zone, where u_1 and v_1 represent the areas planted to crop x_1 in the recharge and the discharge zones, respectively; while u_2 and v_2 represent the areas planted to crop x_2 in the recharge and the discharge zones, respectively. Salinity status of land is represented by *S* and α denotes the discount rate. It is assumed that crop x_1 is more profitable but causes salinity, whereas crop x_2 is less profitable but reduces salinity.

Let the price of crops x_1 and x_2 be p_1 and p_2 respectively. At any time, the profits for the recharge $\left(\pi^{R}\right)$ and the discharge $\left(\pi^{D}\right)$ zones are:

$$\pi^{R}=u_1\left(p_1y_1^{R}-c_1^{R}\right)+u_2\left(p_2y_2^{R}-c_2^{R}\right) \qquad \textbf{(2)}$$

$$\pi^{D}=v_1\left(p_1y_1^{D}(S)-c_1^{D}(S)\right)+v_2\left(p_2y_2^{D}(S)-c_2^{D}(S)\right) \qquad \textbf{(3)}$$

where y_1^{R} and y_2^{R} are crop yields for the recharge zone and, y_1^{D} and y_2^{D} are crop yields for the discharge zone. Similarly c_1^{R} and c_2^{R} are the costs of production for the recharge zone and, c_1^{D} and c_2^{D} are the costs of production for the discharge zone. Note that the y_i^{D}'s are functions of salinity, whereas y_i^{R}'s remain constant. Yields in the discharge zone are estimated by multiplying the expected crop yield ($\bar{y}_i^{D}$) under normal conditions times a growth multiplier (G) that depends on the salinity status of the soil (S) and can be stated as:

$$y_i^D = \bar{y}_i^D \, G_i(S) \qquad i = 1,2 \qquad \textbf{(4)}$$

where G is the damage function:

$$G = k\left[\frac{a}{k}\right] e^{(-r(S\max - S))} \qquad \textbf{(5)}$$

The parameters a, r and k are to be estimated for each particular crop. $S\max$ is the level of salinity beyond which crops won't grow.

The costs of production may also differ between zones because salinity affects costs. A critical assumption in this simple model is that salinity can be reversed through land-use practices. The social discount rate is set at $\alpha = 0.06$ and the private discount rate is $\alpha = 0.10$. The equation of motion for the level of salinity is:

$$S_{t+1} = S_t + \Delta S_t \qquad \textbf{(6)}$$

where, $\Delta S_t = \theta(S, U, V)$ **(7)**

$$= [\gamma_1 u_1 + \gamma_2 u_2]\varphi^R + [\gamma_1 v_1 + \gamma_2 v_2]\varphi^D$$

where, γ_1 and γ_2 are the effects of crops x_1 and x_2 on the level of salinity and, φ^R and φ^D are the portions of the salinity effects that are transmitted to the discharge zone from the recharge and the discharge zones. Note that salinity occurs only in the discharge zone.

In summary, the problem can be stated as:

$$\max_{u_{1t},\, v_{1t}} Z = \int_{t=0}^{T} \left[K^R \pi^R(U_t) + K^D \pi^D(U_t, V_t, S_t)\right] e^{-\alpha t} \qquad \textbf{(8)}$$

Subject to:

$$u_1 + u_2 = K^R \qquad \textbf{(9)}$$

$$v_1 + v_2 = K^D \qquad \textbf{(10)}$$

$$S_{t+1} - S_t = [\gamma_1 u_1 + \gamma_2 u_2]\varphi^R + [\gamma_1 v_1 + \gamma_2 v_2]\varphi^D \qquad \textbf{(11)}$$

$$S_{(0)} = S_0 \qquad \textbf{(12)}$$

$$y_i^D = \bar{y}_i^D \, G_i(S) \qquad i = 1,2 \qquad \textbf{(13)}$$

$$G_i = k_i\left[\frac{a_i}{k_i}\right] e^{(-r(S\max - S_t))} \qquad i = 1,2; t = 1,2,.,T \qquad \textbf{(14)}$$

where K^R and K^D are the total areas of the recharge and the discharge zones, respectively.

Final value of land

The numerical model based on (8) – (14) was solved for $T = 15$ years. Model solution consisted of estimating U_t^* and V_t^*, the optimal values of the decision vectors, model solution also yields the optimal salinity state S_t^*.

The model described above does not assign a final value to the land, and hence the opportunity cost of leaving a degraded resource at the end of the planning period (T) is not included in the evaluation. This causes an “edge effect” in which the land will tend to be degraded as the end of the planning horizon approaches. To prevent this problem the model was solved for a range of salinity levels (from zero to 8 dS/m) and the $TNPV$ Was taken as representing the future value of land.

Based on model results, the final value of land (FV) as a function of salinity was approximated by:

$$FV = \beta_1 + \beta_2 S + \beta_3 S^2 \qquad \textbf{(15)}$$

where parameters β_1, β_2 and β_3 were estimated for both social and private optimisation and the resulting functions are presented in Figure 1. The function provides an excellent fit within the range of results.

The extended form of the objective function is:

$$\max_{u_{1t},\, v_{1t}} Z = \int_{t=0}^{T} \left[K^R \pi^R (U_t) + K^D \pi^D (U_t, V_t, S_t) \right] e^{-\alpha t} + FV(S_T) e^{-\alpha T} \qquad \textbf{(16)}$$

The specification of the variables and the assumptions in the model were the same as in the original model. The same parameter values were used to solve the model with FV.

Parameter values

The parameter values used in the model were largely hypothetical and were set to produce realistic results (Table 1). The values of some parameters are location specific and some are general. A brief description of the numerical values of the variables used in the model is given below.

Land

Land is the main resource in this study. Greiner's (1997, p. 14) report on the Liverpool Plains Catchment reveals that the average farm area in the uphill (the recharge) zone is higher (1210 ha) than in the downhill (the discharge) zone (980 ha) and that the area of cropping in the downhill zone is higher (800 ha) than in the uphill zone (325 ha). For simplicity, we assign equal land area for both zones reflecting concern with total land management and total benefit rather than with unit area management. It is assumed the entire land on each farm could be cultivated with either of the crops.

Crop yield

The two selected crops x_1 and x_2 can be compared with sorghum and lucerne respectively in respect of their return and salinity effects. The study on the Liverpool Plains Catchment revealed that average yield of sorghum under long fallow rotation in the alluvial black soil (the discharge zone) was 4.5 t/ha and that in the red brown earth (the recharge zone) was 2.0 t/ha (Greiner 1997, p. 24). The average yield of lucerne in the same catchment under long fallow rotation in the discharge zone was 2.0 t/ha. The value of crop yields for the two different zones was assigned to reflect the productivity level of the zone and the profitability level of the crops based on experimental values.

Production cost and commodity price

The costs of production of sorghum and lucerne in the Liverpool Plains Catchment were estimated to be $100/ha and $365/ha respectively (Greiner 1994, p. 66). The production cost of lucerne and its yield (2.0t/ha) and price ($120/t) reported by Greiner (1997, p. 24, 1994, p. 66) revealed that it was not profitable and gave negative return.

In this study, the prices of the crops are the same for both zones but the yields and costs change (Table 1).

Salinity effect of crops

The salinity effect of a crop on the soil is measured as dS/m. The process of salinisation is very complex and, therefore, it is not an easy task to estimate the salinity effect of a particular crop directly. For simplicity, a particular value of salinity effect for a crop was assigned. In accordance with the characteristics of the crop and the assumptions, a positive value to crop x_1 (0.005 dS/m) and a negative value to crop x_2 (- 0.010 dS/m) were assigned meaning crop x_1 increases salinity and crop x_2 reduces it. It was assumed the same level of salinity effects for both the recharge and the discharge zone crops.

Proportion of salinity effect

The proportion of salinity effect is the salinity effect from the recharge and the discharge zones actually transmitted to the soil in the discharge zone. The salinity effect originated in the recharge zone reaches the discharge zone. Greiner (1997, p. 25) estimated that 60 per cent of recharge water and 50 per cent of runoff infiltration from the Liverpool range are transmitted and eventually raise the watertable downstream. In this paper we assume that 60 per cent of the effect by the recharge zone crops and 100 per cent of the effect by the discharge zone crops are transmitted as salinity in the discharge zone.

Salinity effects on the yield of selected crops

The level of salinity and the growth response of a particular crop influence crop yields in the discharge zone. A growth multiplier (G) was used to capture the crop growth response to salinity which was obtained from the salinity damage function (equation 5) for the respective crop. The parameters of the salinity damage function were estimated based on experimental data for crop x_1 (NSW Agriculture, Tamworth 1999) and hypothetical data for crop x_2. The function provided a good fit as illustrated in Figures 2 and 3. The yield data were normalised to the range 0-1 to fit function (5). The crop growth decreases sharply as salinity increases and reaches zero at about 9 dS/m.

The parameters of the salinity damage function of crop x_2 were estimated in the same way as for crop x_1. A set of hypothetical data consistent with the assumptions for crop x_2 was used such that the growth (yield) of the crop is less responsive to lower levels of salinity. Figure 3 shows the effect of salinity on growth of crop x_2.

Results of the model without FV

This section presents the results based on the hypothetical data analysed by the simple model which ignored the future value (FV) of land (equation 8). The privately and socially optimal levels of land-use, benefits and salinity effects are presented and compared.

Optimal salinity trajectory

The resulting level of salinity over the planning period depends on the initial salinity status and land use practices of both the recharge and the discharge zones. Under social optimisation, the salinity level becomes zero and remains in steady state until a few years prior to the end of the planning horizon when initial salinity status ranges from zero to 4 dS/m (Figure 4). The rate of decline in salinity is slower for higher initial salinity (8 dS/m) and cannot reach zero within the 15-year planning horizon.

The overall rate of decline in salinity is slow under private optimisation compared to social optimisation (Figure 4). The salinity levels remain about 2 dS/m when initial salinity ranges from zero to 6 dS/m. However, a similar salinity effect was observed at 8 dS/m under both private and social optimisation. The underlying reason is that the higher (8 dS/) initial salinity has such an effect on the growth and productivity of crop x_1 is that the discharge zone can not make profit from crop x_1 and alternatively it produces crop x_2. Hence, the discharge zone produces crop x_2 at the maximum level under both social and private optimisation at this level of salinity, whereas the recharge zone produces crop x_1 at the maximum level to maximise profit.

Maximum TNPV

The Total Net Present Value (TNPV) from crop production for the catchment is the sum of the Net Present Values of the Recharge zone (NPVR) and that of the Discharge zone (NPVD) and they change with the change in salinity status at a given discount rate. The socially optimal Total Net Present Value (TNPVS) assumes that the whole catchment is managed as a single management unit. However, in the case of private optimal Total Net Present Value (TNPVP), the recharge and the discharge zones of the catchment are managed separately and maximise benefits individually.

The higher the initial salinity status, the lower the TNPV because of lower yields (Figure 5). Social benefits (TNPVS) are much higher than private benefits (TNPVP) because of the differences in behavioural assumptions. The distance TNPVS – TNPVP can be interpreted as the welfare loss caused by the salinity externality.

Distribution of benefits

Considering TNPV and its two components NPVR and NPVD for different salinity status under social optimisation, the discharge zone is more productive, produces crop x_1 at the maximum level and obtains a much higher net present value (NPVD) than the recharge zone (NPVR) at zero level of salinity (Figure 6). As the salinity status increases, the gap between benefits to the recharge zone and benefits to the discharge zone decreases, because the discharge zone withdraws land from crop x_1 to produce salinity-reducing crop x_2 as the yield of crop x_1 declines due to salinity. At an initial salinity of 6 dS/m, NPVD and NPVR are equal, and NPVD declines sharply as salinity increases beyond this point.

The results are different under private optimisation; the recharge zone produces crop x_1 at its maximum and gets a low but constant benefit (NPVR) for all levels of salinity at a given discount rate (Figure 6). This occurs because salinity does not have any influence on the productivity and land-use practices in the recharge zone. The discharge zone gets higher net present value (NPVD) than the recharge zone (NPVR) at zero level of salinity, but NPVD declines as initial salinity increases. NPVD lies above NPVR at lower levels of salinity (<2 dS/m) and lies below the NPVR at higher levels of salinity (>2 dS/m).

Results of the model with FV

The model with FV was solved by maximising equation (16) subject to constraints (9)–(14). This section follows the same format as the previous section and highlights the effects of accounting for declining land values caused by land degradation.

Optimal salinity trajectory

The optimal salinity trajectories under social and private optimal land-use at different initial salinity status are presented in Figure 7. Under social optimisation, there was a general trend of sharp declines in the level of salinity over time, except for a high initial salinity (8 dS/m). The higher the level of initial salinity (0 – 6 dS/m), the longer the time required to reach the equilibrium value of zero. Salinity remains in a steady state up to a couple of years before the end of the planning period, when the salinity level increases slightly because crop x_1 is planted at the maximum level to maximise benefit. The highest initial salinity (8 dS/m) under study did not reach zero because of the short time-period considered.

The private optimal salinity trajectory did not reach on a steady state over the period, not even at zero initial salinity, because whatever the level of salinity, the recharge zone produced only crop x_1 and it was up to the discharge zone to produce crop x_2 to reduce salinity, hence forgoing production of crop x_1 up to a certain level. At initial salinity ranges from zero to 2 dS/m, the discharge zone produces crop x_1 up to a certain level, this causes the level of salinity to increase, which then forces a reduced production of crop x_1 and the increase in the level of crop x_2 in the next time period (Figure 7).

Maximum TNPV

The maximum achievable levels of benefits from cropping under social (TNPVS) and private (TNPVP) optimisation at different initial salinity status are presented in Figure 8. As before, the figure shows a higher level of benefit under social optimisation than under private optimisation. The ratios of benefits between them (TNPVS and TNPVP) ranges from 0.51 to 0.59 depending on salinity (Table 2). The two main reasons for the variation are: *First*, the social optimal land-use decisions were taken at catchment scale, where the whole catchment was considered as a single management unit and, therefore, the more productive discharge zone was given priority to produce crop x_1. In contrast, individual-farm level land-use decisions ignored this comparative productivity principle and the less productive recharge zone produced crop x_1 in the entire land. The resulting higher level of salinity emergence forced the discharge zone to reduce salinity by producing more of crop x_2. *Second*, individual farmers were assumed to use a higher discount rate (10 %) than society (6%), which affected discounted income.

Distribution of benefits

The distributions of benefits between the recharge and the discharge zones under social and private optimisation are presented in Figure 9. Under private optimisation, the recharge zone obtained a constant rate of benefit (NPVR) for all levels of salinity, however, the discharge zone's benefit (NPVD) declined with increases in salinity. The benefits of the two zones became equal at a salinity level of about 2 dS/m and, the discharge zone benefits (NPVD) fell below the recharge zone benefit (NPVR) thereafter. Under social optimisation, the discharge zone obtained a higher benefit than the recharge zone at salinity levels below 7 dS/m. It was estimated that the discharge zone obtained 63 to 213 per cent increased benefits depending on salinity (Table 3). On the other hand, the recharge zone obtained 17 to 75 per cent increased benefit at salinity 6 to 8 dS/m but lost (sacrificed) 5 to 10 per cent benefit at salinity zero to 4 dS/m in comparison to private optimisation. Note that under social and private optimisation land-use decisions in the recharge and the discharge zones were the same at salinity 8 dS/m.

Impact of using FV in the model

The results of models with and without FV were discussed in the previous sections. The impact of FV on salinity trajectory is presented in this section.

Salinity trajectory

The optimal salinity trajectories were affected by the introduction of FV into the model, under both social and private optimisation (compare Figures 4 and 7). Under social optimisation, the overall rate of decline in salinity was faster with FV than without FV. The initial salinity levels of 2 dS/m and 4 dS/m declined to zero in years 3 and 4 respectively for both models. However, at an initial salinity level of 6 dS/m, optimal salinity declined to zero in year 8 with FV compared to year 11 without FV.

In the case of with FV, the salinity level became zero and remained in a steady state until year 14 for initial salinity levels zero to 4 dS/m, whereas, salinity started to increase in year 13 at an initial salinity level of 6 dS/m. The salinity level did not reach zero when initial salinity was 8 dS/m.

The effects of FV is more obvious under private optimisation (compare Figures 4 and 7), the level of salinity declined for longer and reached a lower level with FV than without FV. With FV the salinity level fluctuated between zero and 1 dS/m for all initial salinity levels except 8 dS/m.

Welfare loss to society

The question of welfare loss arises because the land-resource is not used efficiently under private management in the presence of externalities. Welfare loss is the amount of benefits (TNPV) forgone by society. The difference in benefits between social and private management is the welfare loss (Figure 10). Depending on initial salinity, welfare loss ranges from $44,588 to $105,151 at 6 per cent discount rate and from $23,511 to $64,537 at 10 per cent discount rate (Table 4). The levels of loss are inversely related to the levels of salinity.

Common property and socially optimal land-use

Common property has long been debated in relation to its definitional aspects and application to natural resource management. Before going any further, the conventional definition on common property given by Stevenson (1991) is considered. “Common property is a form of resource management in which a well-delineated group of competing users participates in extraction or use of a jointly held, fugitive resources according to explicitly or implicitly understood rules about who may take how much of the resource” (Stevenson 1991, p. 46).

The term common property is often misunderstood and mixed up with the definitions of open access and no property. The problem with Hardin's (1968) definition of common property as a synonym for open access in his 'tragedy of the commons' paper was discussed by Quiggin (1986, p. 104), who states that the system described by Hardin did not exist ever. According to Quiggin (1986), 'the actual commons were not open to all comers but the property of a defined group, known as *commoners*.' He also states that common property systems contain well-defined rights to use and manage resources within the group.

According to Miller (1982), common property resources are owned by everyone and therefore owned by no one. Following this so called traditional definition Gomboso and Hertzler (1991) examined the relationship between common property and dryland salinity and concluded: 'changes in groundwater flux across farm boundaries caused by clearing, agronomic and engineering practices is a root cause of common property'.

The two common alternative approaches used by economists to deal with externality problems in natural resource management are the Pigovian and the Coasian approaches. The Pigovian approach imposes a tax on pollution activities to internalise the externalities, which requires accurate estimation of the external cost function. Hodge (1982) criticises the Pigovian approach and states that it is difficult to specify an appropriate tax base. He also points out it has rarely been adopted because levying a tax on polluters means a higher burden than if they were merely required to adopt pollution control measures yielding the same level of abatement. On the other hand, the Coasian approach requires allocation of private property rights with respect to pollution activities which are inherent the conflict between stability and efficiency (Quiggin 1986, p. 110). The problems associated with the Coasian type property rights suggest the necessity of alternative property rights to consider.

To overcome the shortcomings of the Coasian approach, Quiggin (1986) developed a common property analysis framework based on the concept of asset value. He states that it works well in the cases where damage is perfectly reciprocal or when the distribution of costs and benefits is symmetrical. But, dryland salinisation, in cases such as the Liverpool Plains Catchment, is unilateral and may not be solvable through Quiggin's common property approach.

The results of the present study reveal that socially-optimal land-use in a salinity-affected catchment does not coincide with the private optimal because of the externality. The paper shows how to calculate the welfare loss to society. As pointed out by Quiggin the farmers of a catchment, such as the Liverpool Plains, enjoy private ownership over land, however, they share common aquifers for accessing groundwater systems. On this ground, common property rights may be exercised over the aquifers by the farmers. For simplicity, it may be assumed that only the farms in a catchment are responsible for causing salinity, and salinity affects only those farms. The basic idea of common property right is that the farmers in the discharge zone have the right not to have their soil salinised and the recharge zone farmers do not have the right to cause salinity.

Under the common-property solution, the discharge zone farmers of the catchment are better off and the recharge zone farmers are worse off than under private management. Although, the catchment as a whole is better off under socially-optimal land-use solution, the recharge zone farmers may not be willing to adopt the socially optimal land-use plan because they are worse of under this system. The Coasian-type market framework may provide the basis for a legal bargain between farmers in the two zones to determine a compensation mechanism for sacrifices made by recharge-zone farmers. This can be measured with the model presented here.

Conclusion

A simple dynamic optimisation model was applied to find the optimal land-use mix that maximises benefits for a salinity-affected catchment consisting of a recharge and a discharge zone. The parameter values used in the model runs were mostly hypothetical, but they were assigned in accordance with realistic assumptions and consistent with some experimental values.

The effect of ignoring the final land value in dynamic models is illustrated. The catchment-scale optimisation results revealed that, under the given assumptions, it was efficient to follow sustainable land-use systems.

Welfare losses experienced under individual farm-level optimisation were shown to be significant. These losses could be avoided by adopting management based common property of the underground aquifer.

Common-property rights over the groundwater aquifers of the farmers with a provision to compensate the losers may be able to internalise the externalities and may achieve socially optimal land-use.

This paper presents general results and no sensitivity analysis was undertaken. This is an important task for further research.

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Figure 1: Estimated land value as affected by salinity

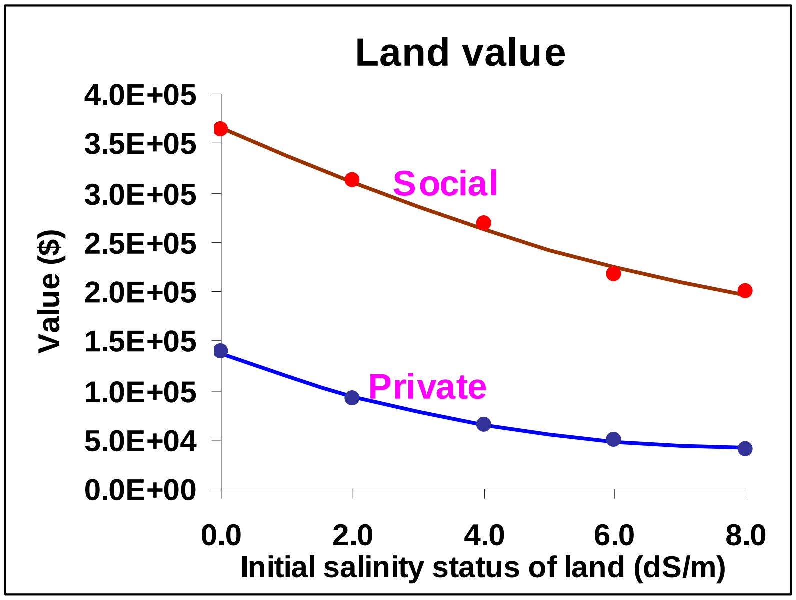
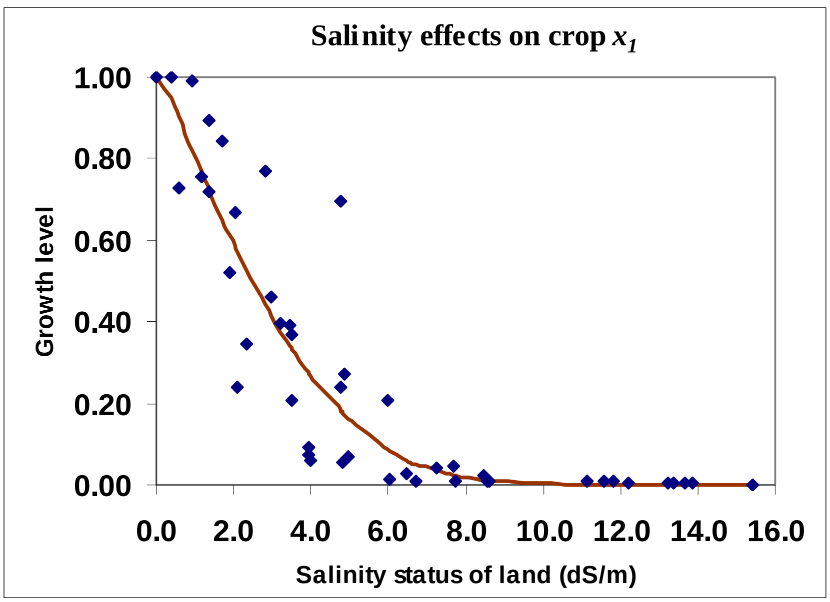


Figure 2: Salinity effect on crop x_1 (Sorghum)



Source: NSW Agriculture, Tamworth (1999).

Figure 3: Salinity effect on crop x_2 (hypothetical)

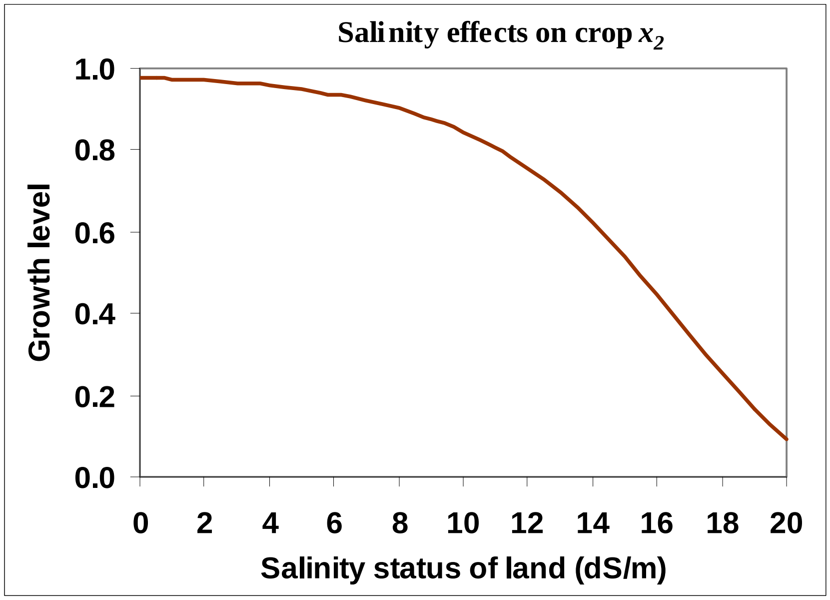


Figure 4: Optimal salinity trajectories under social and private optimisation

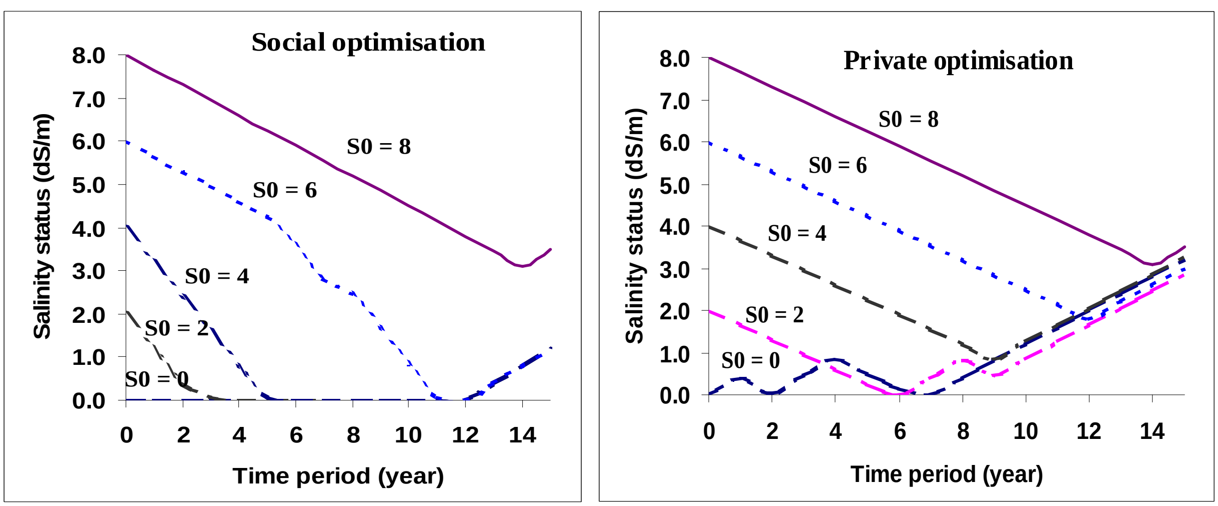


Figure 5: Maximum level of TNPV under social and private optimisation

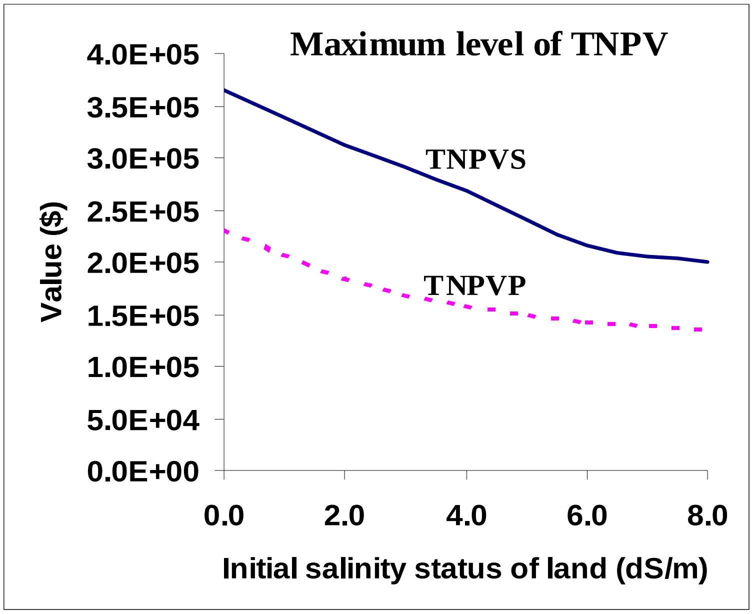
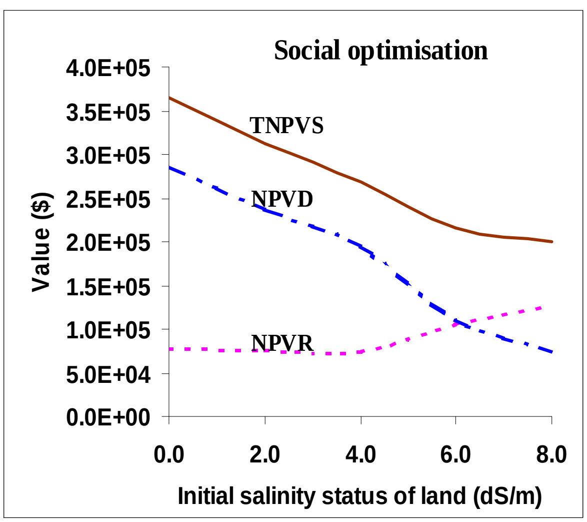


Figure 6: Distribution of benefits between the zones under social and private optimisation



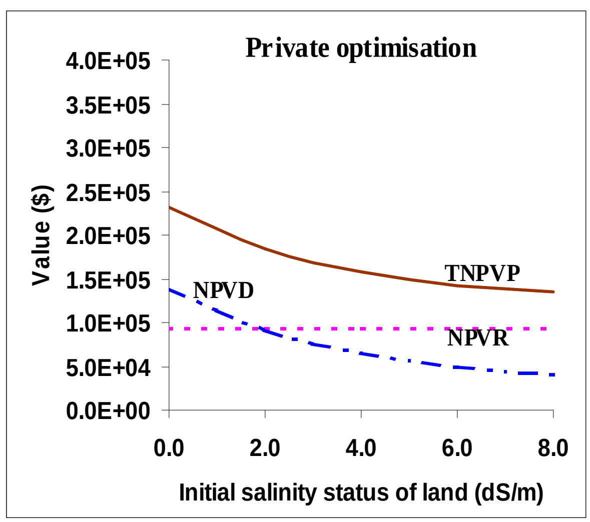
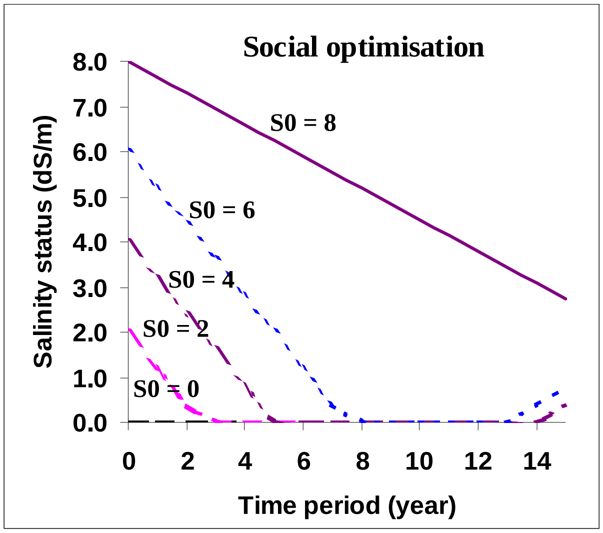


Figure 7: Salinity trajectories under social and private optimisation with FV



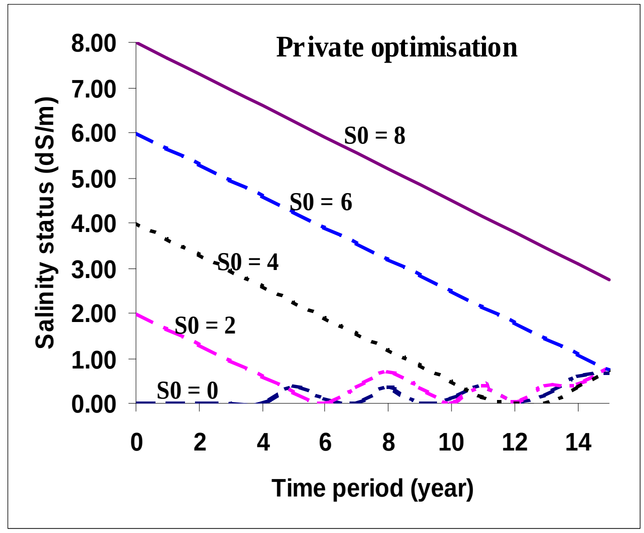


Figure 8: Maximum level of TNPV under social and private optimisation with FV

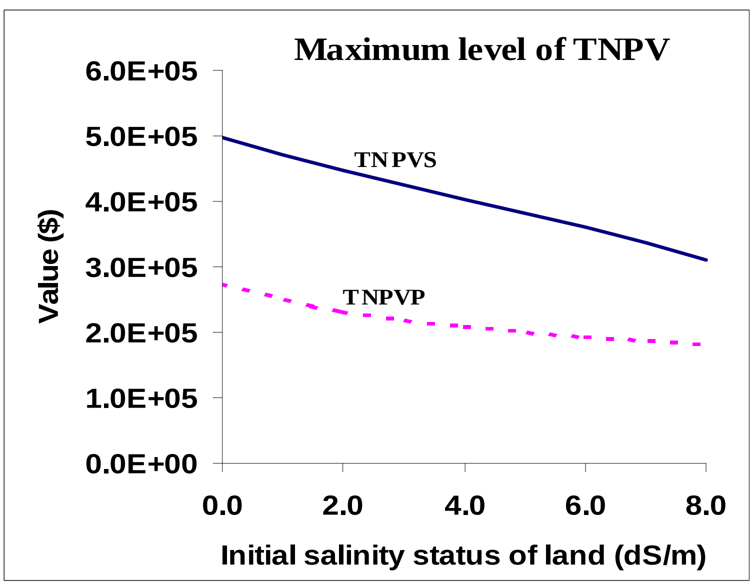


Figure 9: Distribution of benefits between the zones under social and private optimisation with *FV*

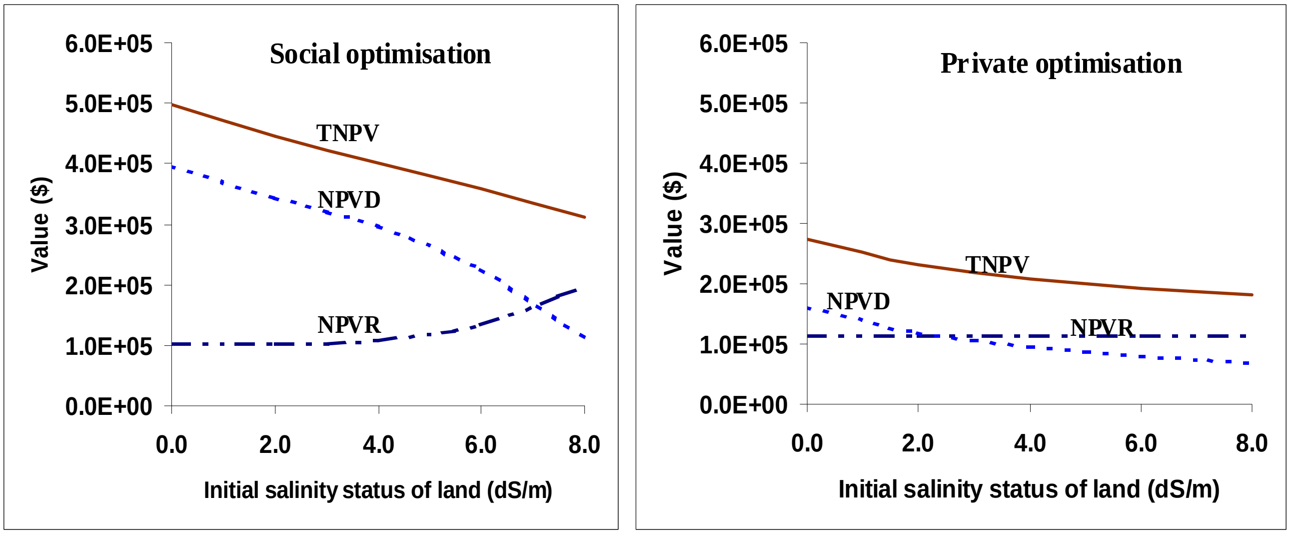


Figure 10: Welfare loss to society under with and without FV

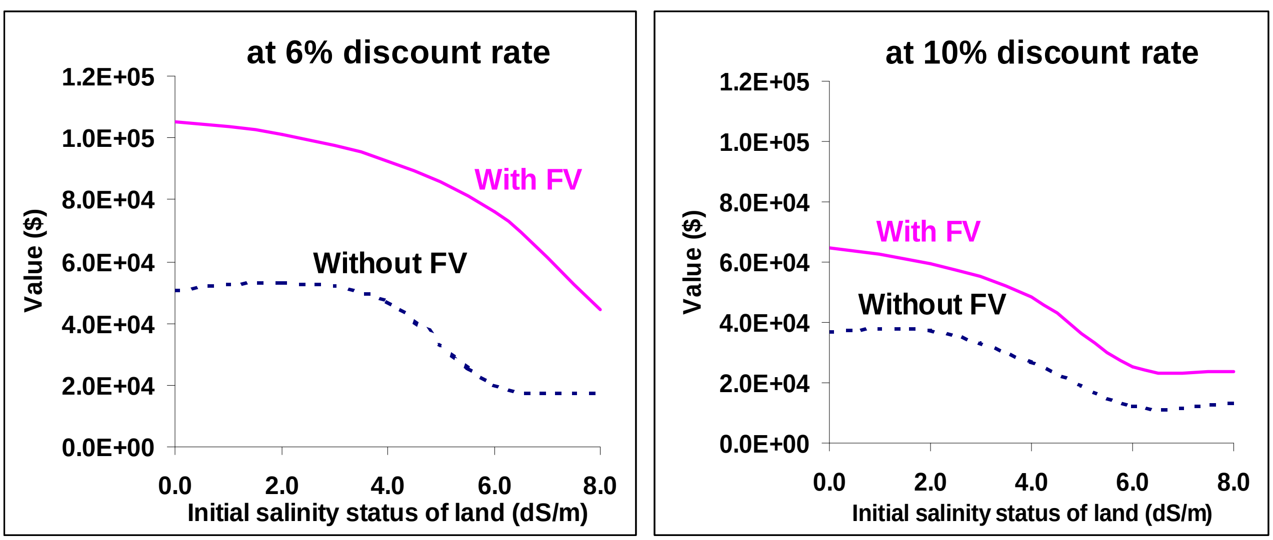


Table 1: Model parameter values

Parameter name	Notation		Value	
	Recharge	Discharge	Recharge	Discharge
Land area (ha)	K^R	K^D	50	50
Yield of crop x_1 (t/ha)	y_1^R	y_1^D	3.0	-
Yield of crop x_2 (t/ha)	y_2^R	y_2^D	2.0	-
Expected yield of crop x_1 (t/ha)	-	$\bar{y}_1$	-	5.0
Expected yield of crop x_2 (t/ha)	-	$\bar{y}_2$	-	2.5
Cost of production of crop x_1 ($/ha)	c_1^R	c_1^D	140	160
Cost of production of crop x_2 ($/ha)	c_2^R	c_2^D	100	120
Price of crop x_1 ($/t)	p_1	p_1	140	140
Price of crop x_2 ($/t)	p_2	p_2	120	120
Salinity effect of crop x_1 (dS/m)	γ_1	γ_1	0.005	0.005
Salinity effect of crop x_2 (dS/m)	γ_2	γ_2	-0.01	-0.010
Proportion of salinity effect	φ^R	φ^D	1.0	0.6

Table 2: The ratios of benefits between social and private optimisation

Salinity status (dS/m)	Total net benefits in dollars		Ratio of private and social benefits (private/social)
	Social	Private	
0.0	498,092	272,982	0.54
2.0	446,077	231,736	0.52
4.0	402,092	206,909	0.51
6.0	359,792	192,169	0.53
8.0	310,577	182,167	0.59

Table 3: The change in benefit share between social and private optimisation

Salinity Status (dS/m)	Net benefit in Dollars				% increase in benefit due to switching private into social optimisation	
	Social optimisation		Private optimisation			
	Recharge	Discharge	Recharge	Discharge	Recharge	Discharge
0.0	101,680	396,412	112,465	160,516	-10	147
2.0	102,887	343,190	112,465	119,271	-9	188
4.0	106,669	295,423	112,465	94,443	-5	213
6.0	133,910	225,882	112,465	79,704	19	183
8.0	197,117	113,460	112,465	69,702	75	63

Table 4: The extent of welfare loss to society

Salinity status (dS/m)	Welfare loss in dollars		Ratios of welfare loss (10% discount/6% discount)
	At 6% discount	At 10% discount	
0.0	105,151	64,537	0.61
2.0	101,074	59,309	0.59
4.0	92,439	48,268	0.52
6.0	76,279	25,232	0.33
8.0	44,588	23,511	0.53