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REVEG

A Model for Predicting Costs and Benefits of Recharge Reduction Strategies in the Mallee Region of South Australia

P.G. Cook and J. Connor

CSIRO Land and Water
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CSIRO LAND and WATER

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A Model for Assessing Costs and Benefits of Recharge Reduction Strategies in the Mallee Region of South Australia

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Prepared for the Murray Mallee Local Action Planning Association

Natural Heritage Trust
Helping Communities Helping Australia

MURRAY MALLEE
Local Action Planning Association Inc.

CSIRO

Government of South Australia

ABSTRACT

In the mallee region of South Australia, clearing of native Eucalyptus vegetation and its replacement with annual crops and pastures has increased rates of aquifer recharge. This has led to increased flows of saline groundwater into the Murray River, with consequent increases in river salinity. These saline groundwater flows are predicted to continue to increase over the next hundred years and beyond. One of the management options being considered is revegetation to reduce groundwater recharge.

REVEG is a spreadsheet model that allows the costs and benefits of revegetation strategies to be assessed. The model is very flexible, and allows the user to specify a range of hydrogeological conditions, and also land management options and their associated costs and productivities. The model calculates private and public net present values of landuse options, and also salinity benefits to the Murray River. A 200-year time frame has been adopted, but calculations can also be performed for any chosen target year (not exceeding 200 years).

The model is intended to be an education and communication tool for use by the Murray Mallee Local Action Planning Association. The authors would caution against its use for policy formulation without seeking further scientific and technical advice.

INTRODUCTION

In the mallee region of South Australia, clearing of native Eucalyptus (mallee) vegetation and its replacement with annual crops and pastures has increased flows of saline groundwater into the Murray River. The native vegetation is extremely water-efficient, and its roots may extend to 20 m depth. Several studies have shown that rates of groundwater recharge under native mallee vegetation are less than 0.1 mm/yr (Allison et al., 1990). Clearing of the native vegetation, and its replacement with shallow-rooting crops and pastures results in increases in the amount of water draining below the plant root zone. The increase in drainage, once transmitted to the water table, causes the water table to rise, increasing hydraulic gradients towards the Murray River. Because the groundwater adjacent to the river is saline, this causes increased flows of saline groundwater into the river, and hence increases in river salinity.

One of the management options being considered to reduce the flow of saline groundwater to the river is revegetation to reduce groundwater recharge. However, the timescales associated with this strategy may be quite long. Jolly and Cook (2002) and Cook et al. (2001, 2002) have recently modelled the time delay associated with this process, using both analytical and numerical modelling techniques. Figure 1 shows the reduction in groundwater discharge to the Murray River as a function of time, resulting from revegetation along a 5 km strip adjacent to the river, for a sandy loam soil and water table depths before revegetation of 10 m and 40 m. These calculations assume that revegetation prevents additional drainage below the land surface, but does not allow plants to extend roots deeply into the soil to ‘mine’ existing soil water.

REVEG is a simple spreadsheet model that allows the costs and benefits of revegetation strategies to be assessed. The model is very flexible, and allows the user to specify a range of hydrogeological conditions, and also land management options and their associated costs and productivities. The model calculates private and public net present values of landuse options, and also salinity benefits to the Murray River. The salinity benefits to the river are expressed in terms of EC benefits, which represent the lowering of salinity (in EC units, μS/cm) due to land management change relative to the do nothing scenario. A 200-year time frame has been adopted, but calculations can also be performed for any chosen target year (not exceeding 200 years).

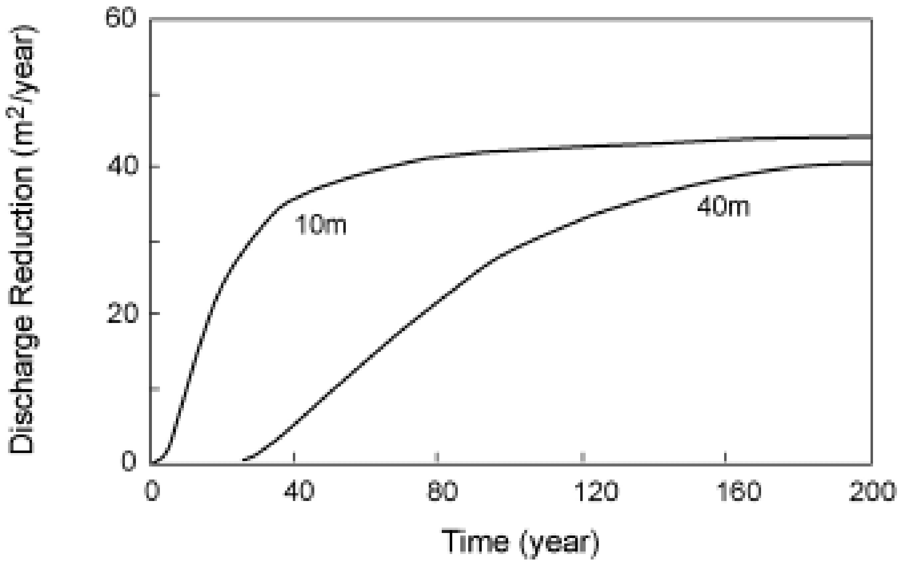


Figure 1. Reduction in groundwater discharge to the river as a function of time since revegetation, for revegetation of a 5 km strip adjacent to the river. Simulations are for a sandy loam soil and water table depth of 10 m and 40 m. Before revegetation, deep drainage and recharge were equal to 10 mm yr^{-1}. Eventually, the discharge reduction is equal to 50 $m^2\ yr^{-1}$, which is equal to the width of the revegetation strip (5 km) multiplied by the recharge reduction (10 mm yr^{-1}). Assuming a groundwater salinity of 20 000 mg/L, this represents a decrease in salt load to the river of 2.7 tonnes $day^{-1}\ km^{-1}$. From Cook et al. (2001).

So that the important hydrogeological and economic processes could be depicted using a spreadsheet model requiring a limited amount of input data, a number of assumptions are made:

- It is assumed that the deep unsaturated zone soils (below 2 m) comprise loamy sands, and that heavy clay layers (such as the Blanchetown Clay) that would impede water movement are not present.
- The model assumes a constant value of deep drainage for the area to be revegetated.
- It is assumed that revegetation reduces deep drainage to zero immediately, but does not allow plants to extend roots deeply into the soil to ‘mine’ existing soil water below a depth of 5 m.

While we have included default values for a number of the model parameters in the spreadsheet (and some of these values are used as examples), the values may not be appropriate for any particular situation. The examples are provided for illustration purposes only. The model is intended to be an education and communication tool for use by the Murray Mallee Local Action Planning Association. The authors would caution against its use for policy formulation without seeking further scientific and technical advice.

MODEL INSTRUCTIONS

The program is an Excel-spreadsheet model. It requires Microsoft Excel 2000™ with Analysis Toolpak Add-In™. A full description of the model is provided in Appendix 1. There are seven pages that can be accessed by the user. The TITLE page contains a short description of the model, and the INSTRUCTIONS page contains simple instructions for use. The RECHARGE page is the first page that requires input from the user. On this page, the soil texture (sand, loamy sand, sandy loam, loam, clay loam, sandy clay or clay) is entered using the drop-down menu. The model then estimates a deep drainage rate for that soil type, and this value is displayed. The user also enters the watertable depth at the site, and the number of years since the land was cleared. The graph on this page will then show the expected rate of recharge to the aquifer under continuation of the current land use, and following immediate revegetation.

On the SALT LOAD page, the user enters the revegetation area (in hectares), and the distance of the site from the Murray River. The aquifer transmissivity and groundwater salinity are also required, and these can be determined from the maps provided in Appendix 2. The graph will then show the expected reduction in salt load to the Murray River due to revegetation.

The economics module calculates private and public benefits of revegetation. On the ECONOMICS page, choose one of the revegetation options using the pull down menu at the top of the sheet. It is reproduced below (Figure 2).

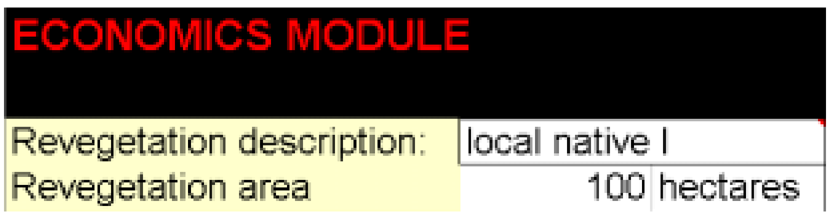


Figure 2: Top of the economics worksheet

You can define the establishment and annual expenses, yield units, rotation length, prices received, and schedule of up to eight harvests for up to four revegetation options on the COSTS AND YIELD worksheet.

ECONOMIC COSTS AND PRODUCTIVITY

public benefit discount rate	3.00%	EC/100 salt tonnes day^{-1}	25.00
annual interest rate	8.00%	$ / EC unit	$117,500
opportunity cost/hectare	$40		

Figure 3: Top of the Costs and Yield worksheet

The top of the COSTS AND YIELD worksheet is reproduced as Figure 3. As you can see you will have to enter values for five parameters that will be used in economics calculation for all options:

1. Public Benefits Discount Rate - Enter the annual rate of discounting for public benefits. While 7% or 8% rates are commonly used and recommended by NSW treasury, there are also good arguments for lower rates (2% to 4%) when public environmental benefits are involved. You may wish to test sensitivity of results to this assumption by recalculating economics at different rates.

2. Annual Interest Rate - Enter the annual rate of interest you have to pay for business borrowing. (This cell is formatted as a percentage so you must enter a value between 0 and 100.)

3. Opportunity Cost - Enter the per hectare return net of all variable costs you would earn from the best alternative use of the land.

4. EC/100 salt tonnes day^{-1} - Tonnes of salt convert to salinity damage (measured as EC units at a standard reference point, Morgan, SA) at different rates for different river reaches. Refer to Figure 19 in Appendix 2 to find the value for the river reach you are evaluating.

5. $ / EC unit - Enter the value of lost agricultural productivity and urban water infrastructure damages resulting from a one EC unit. At the time this program was written, the MDBC was using values between $93,000 and $142,000 per EC unit at Morgan, SA for SA Riverland sites (MDBC, 2000). A suggested default value is the mid-point value of $117,500/ EC unit. Though it should be noted that these values are likely to change as new studies become available.

The first option on the top right of the worksheet is native revegetation. The area where you'll need to enter inputs for computing the economics of native revegetation is reproduced below.

Input costs, yields, prices, hectares		harvest	year	yield/ha
revegetation description:	local native species	1	0	0
hectares planted	100	2	0	0
yield units		3		
length of rotation (years)	30	4		
establishment expense($/ha)	$750.00	5		
annual expense($/ha)	$0.00	6		
price/yield unit	$0.00	7		
native species planting?	yes	8		

Figure 4: Input area on the Costs and Yield Worksheet

On the left hand side of the menu, six inputs are required

1. Revegetation description – A word or two describing the type of revegetation (I.e. woodlot, or native revegetation)

2. Yield units - Enter yield units (i.e. tonnes)

3. Length of rotation – In the case of vegetation that you expect to harvest, enter the number of years until the vegetation will have to be re-established. In the case of native vegetation where no harvest or need to re-establish is expected, enter the number of years over which you wish to amortise establishment cost.

4. Establishment expense ($/ha)- Enter the per hectare cost of vegetation establishment.

5. Annual expense ($/ha)- Enter the per hectare annual costs of maintaining the vegetation.

6. Price / yield unit - Enter the amount you expect to earn per unit harvested in today's dollars.

7. Native species planting? – This is a pull down menu. Choose yes if the vegetation option that will be established is not to be harvested. Choose no if the vegetation option is planted with the intent of harvesting or grazing.

On the right hand side of the input area you will enter an anticipated harvest schedule. This involves entering the years after planting that each harvest is expected and the yield per hectare anticipated.

Several measures of public and private economic returns are produced on the ECONOMICS and ECONOMICS GRAPHS worksheets. Interpretation of these outputs is provided with reference to two illustrative examples in the next section.

EXAMPLE1

This example calculates the costs and benefits associated with revegetation with native mallee. The example is for a revegetation project on an area of 100 hectares, located 2 km from the Murray River, southeast of Mannum. The site was cleared of native vegetation 70 years ago, has a loamy sand soil texture and a watertable depth of 30 m. The aquifer transmissivity is 75,000 m^2/yr and the groundwater salinity adjacent to the river is 10,000 mg/L.

Recharge

On the RECHARGE page, we select the loamy sand soil texture, and enter a water table depth of 30 m and a time since clearing of 70 years. The model calculates that the deep drainage rate for a loamy sand soil is 20 mm/yr, but that this has not yet reached the aquifer (thus the graph shows a recharge rate of zero at time zero). If the current land use continues (no change), it is calculated that the recharge rate will increase to 20 mm/yr in 20 years from now. If the area is revegetated immediately, then the recharge rate would begin to decrease in approximately 50 years. One hundred years from now, the recharge rate would be approximately 2 mm/yr (Figure 5).

Salt Load

On the SALTLOAD page, we enter a contributing area of 100 hectares, a distance to the river of 2000 m, aquifer transmissivity of 75,000 m^2/yr, and groundwater salinity of 10,000 mg/L (Figure 6). The model predicts that the salt load to the aquifer would begin to decrease in approximately 50 years (when the recharge rate begins to decrease). After 100 years the reduction in salt load would be approximately 0.3 tonnes/day.

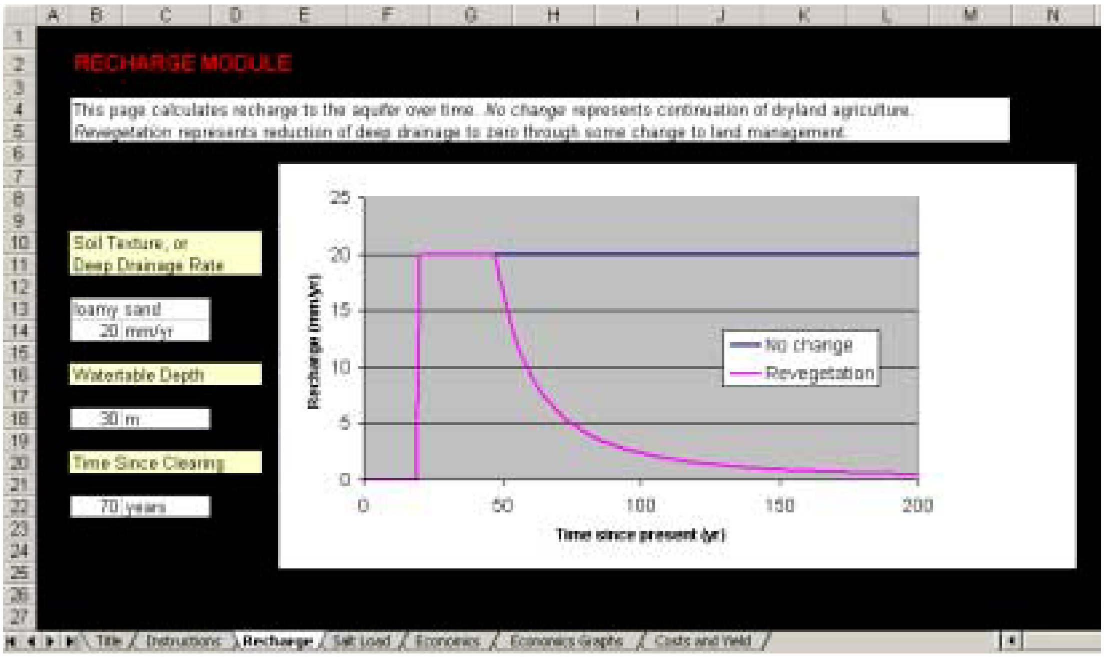


Figure 5. Recharge worksheet for example 1.

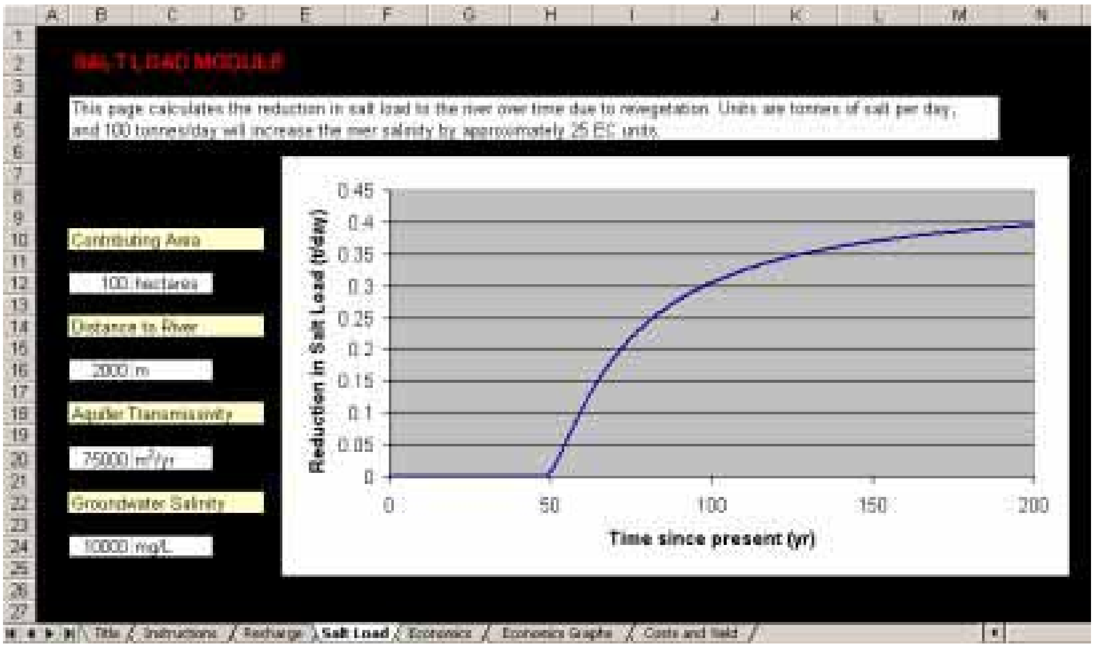


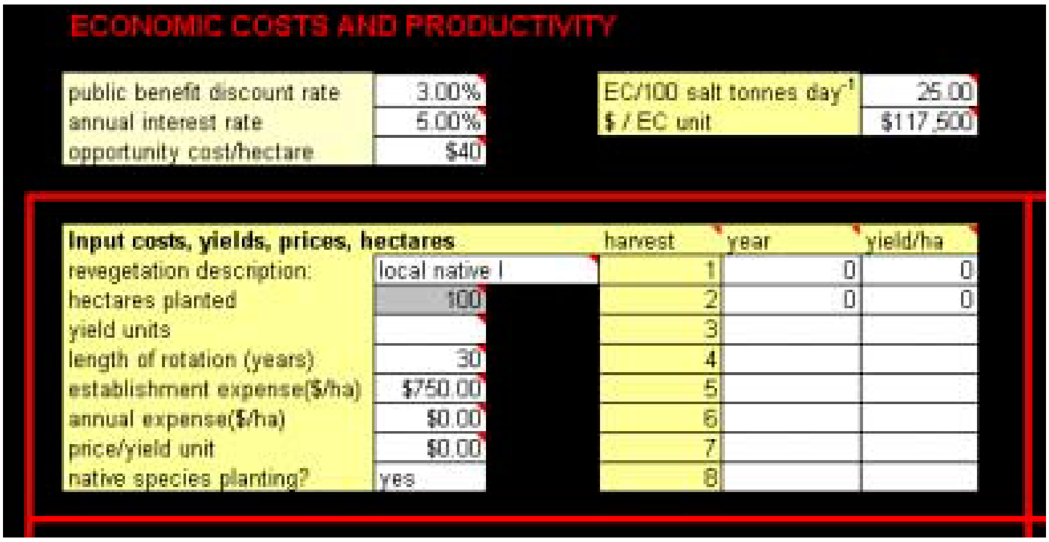
Figure 6. Salt load worksheet for example 1.

Economics Evaluation

The first step in economic evaluation is to fill in the costs of establishing and maintaining native vegetation on the COSTS AND YIELD worksheet. At the top, we have chosen a real public benefit discount rate of 3%, and a real annual cost of borrowing of 5%. An opportunity cost of $40/ha is entered (the expected return to the default use of the land - sheep wheat rotation). Next, establishment and annual costs are entered as shown in Figure 7. Notice that a rotation length of 30 years is entered, even though no harvest or re-establishment of the native vegetation is expected. This is because, the program user wishes to assess the economics of amortising the establishment cost over 30 years.

To view the results describing private and public economics of native vegetation, tab back to the ECONOMICS worksheet. The section entitled PRIVATE RETURNS OVER ROTATION PERIOD in Figure 8 shows that because native vegetation has no expected sales return but involves significant costs, the net present value of this option is a negative (-$140,490) and on an annualised per hectare basis the option costs about $91/annum more than the next best alternative. Because no sales revenue is expected there is no break-even year.

On the private cash flow graph on ECONOMICS GRAPHS worksheet reproduced in Figure 9, it can be seen that a large initial establishment cost is involved, but in future years only opportunity costs are incurred and the discounted value of opportunity costs become quite small after 20 years.



ECONOMIC COSTS AND PRODUCTIVITY

public benefit discount rate	3.00%
annual interest rate	5.00%
opportunity cost/hectare	$40

EC/100 salt tonnes day^{-1}	25.00
$ / EC unit	$117,500

Input costs, yields, prices, hectares	
revegetation description:	local native l
hectares planted	100
yield units	
length of rotation (years)	30
establishment expense($/ha)	$750.00
annual expense($/ha)	$0.00
price/yield unit	$0.00
native species planting?	yes

harvest	year	yield/ha
1	0	0
2	0	0
3		
4		
5		
6		
7		
8		

Figure 7. Costs and Yield worksheet for example 1.

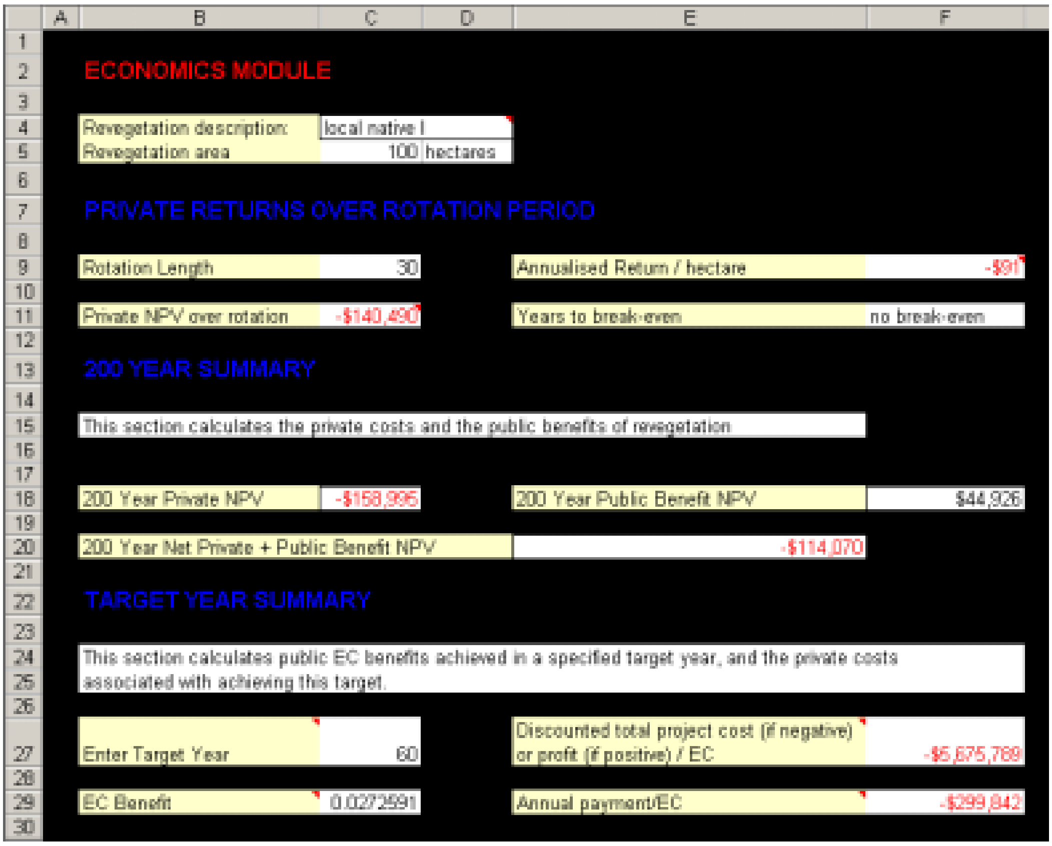


Figure 8. Economics worksheet for example 1.

The 200 YEAR SUMMARY section of the ECONOMICS worksheet shows three summary measures of public and private benefits computed over a 200 year time horizon. The annual dollar value of public benefits used in computations is based on estimates of agricultural productivity losses and urban water infrastructure damages resulting from salinity (MDBC, 2000). The results shown in Figure 8 show that the discounted value of future public benefits over a 200 year horizon in this example is $44,926, and the discounted value of private cost is -$158,995. Because public benefits don't fully offset private costs, the NPV of private plus public benefits is -$114,070.

As can be seen on the public and private benefits graph on the ECONOMICS GRAPHS worksheet (Figure 9), in real (undiscounted) dollars public benefits start accruing after about 50 years but annual public benefits quickly thereafter grow to exceed private costs.

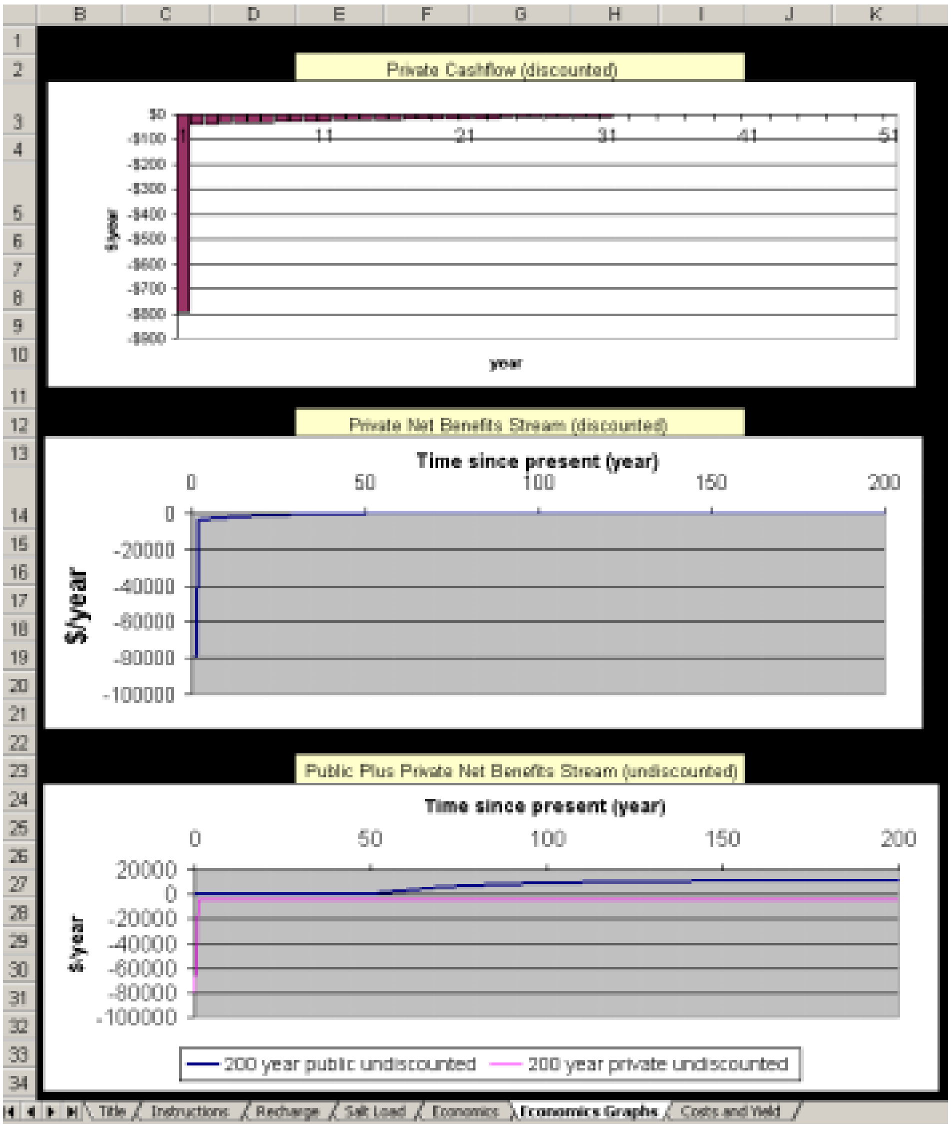


Figure 9. Economics graphs worksheet for example 1.

The TARGET YEAR SUMMARY section of the ECONOMICS worksheet calculates the discounted private cost or profit of achieving the public EC benefits that result from a revegetation option in a specified target year. In this example, the user entered a target year value of 60 (i.e., 60 years from present). Results in the EC Benefit cell indicate that a 0.0273 EC unit salinity loading reduction can be expected in 60 years if native vegetation is planted on the 100 hectare site today. Results in the Discounted Total Project cost or profit / EC cell indicate that discounted sum of cost per EC benefit for the revegetation option is -$5,675,789.

EXAMPLE 2

This example calculates the costs and benefits associated with revegetation by establishing a saltbush planting to complement a sheep grazing operation. The example is for an area of 100 hectares, located 2 km from the Murray River. The site was cleared of native vegetation 100 years ago, has a sandy soil texture and a watertable depth of 20 m. The site is located east of Blanchetown, where the relevant aquifer transmissivity is 180,000 m^2/yr and the groundwater salinity adjacent to the river is 10,000 mg/L.

Recharge

On the RECHARGE page, we select the sand soil texture, and enter a water table depth of 20 m and a time since clearing of 100 years. The model calculates that the deep drainage rate is currently 30 mm/yr, and that this has already reached the aquifer (thus the graph shows a recharge rate of 30 mm/yr at time zero). If the area is revegetated immediately, then the recharge rate would begin to decrease in 21 years. Fifty years from now, the recharge rate would be approximately 5 mm/yr (Figure 10).

Salt Load

On the SALTLOAD page, we enter a contributing area of 100 hectares, a distance to the river of 2000 m, aquifer transmissivity of 180,000 m^2/yr, and groundwater salinity of 10,000 mg/L. The model predicts that the salt load to the river will begin to decrease in 22 years. After 50 years, the reduction in salt load will be approximately 0.45 tonnes/day (Figure 11).

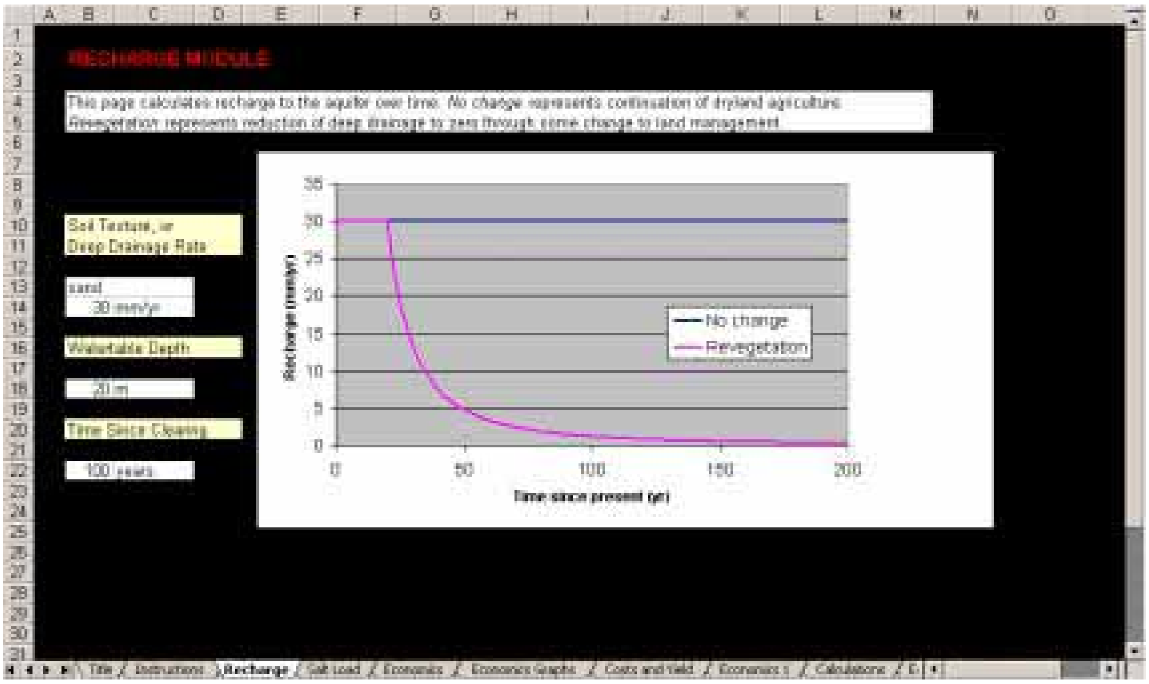


Figure 10. Recharge worksheet for example 2.

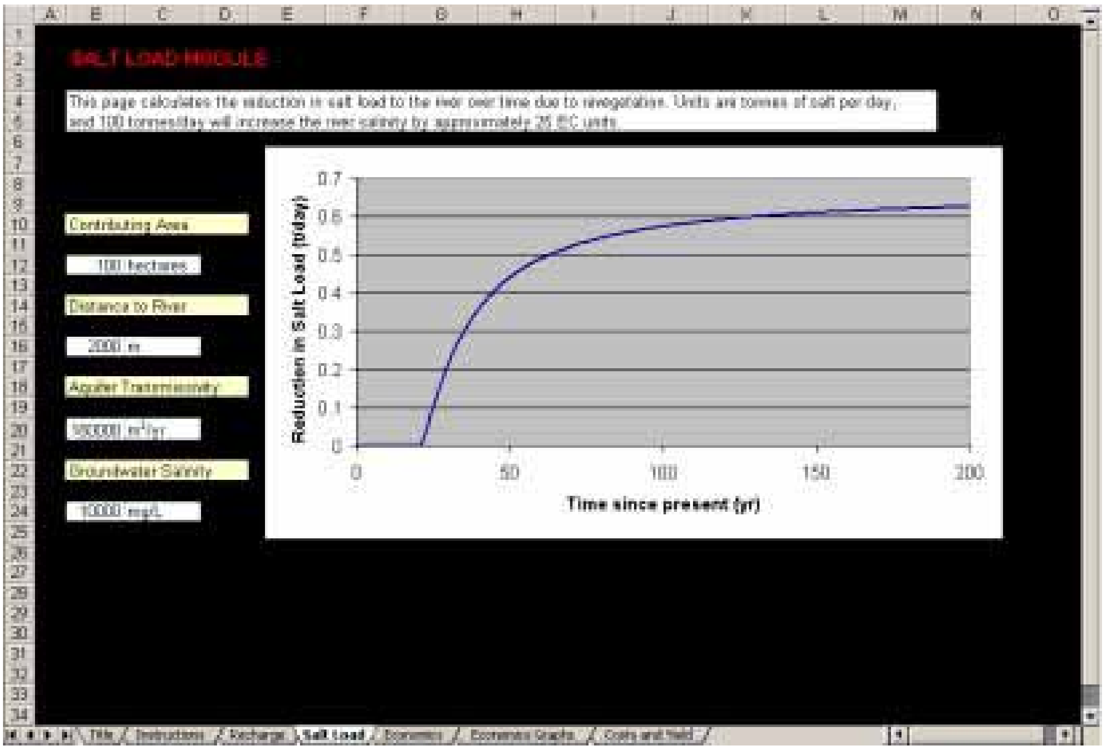


Figure 11. Salt load worksheet for example 2.

Economics Evaluation

The first step in economic evaluation is to fill in values at the top of the COSTS AND YIELD worksheet. It is assumed that this is done the same way in example two as is it was in example one (see Figure 7 on page 12).

Next the costs and yields are filled in. As a revegetation description we typed in ‘saltbush - pasture’. For yield units we’ve typed in “dse” for dry sheep equivalent (though this entry is also not strictly necessary). In the rotation length cell a value of 16 was entered. Values entered in the next four cells are establishment expense ($/ha) = 500, annual expense = 0 (because no value was entered), price/unit yield = $4 (the fodder value of the saltbush grazing), and native species planting = no.

It is expected that the saltbush will go 16 years before replanting is required. And that after the second year 2.9 dse will be available for grazing each year/ha. To fit this into that eight available harvests on the harvest schedule a year two harvest of 2.9 dse is assumed, and it succeeding years a 5.8 (2*2.9 dse) harvest is assumed in every second year through the end of the rotation (year 16).

Input costs, yields, prices, hectares		harvest	year	yield/ha
revegetation description:	saltbush - pasture	1	2	2.9
hectares planted	100	2	4	5.8
yield units	dse	3	6	5.8
length of rotation (years)	16	4	8	5.8
establishment espense($/ha)	$500.00	5	10	5.8
annual expense($/ha)		6	12	5.8
price/yield unit	$4.00	7	14	5.8
native species planting?	no	8	16	5.8

Figure 12. Costs and yield worksheet for example 2.

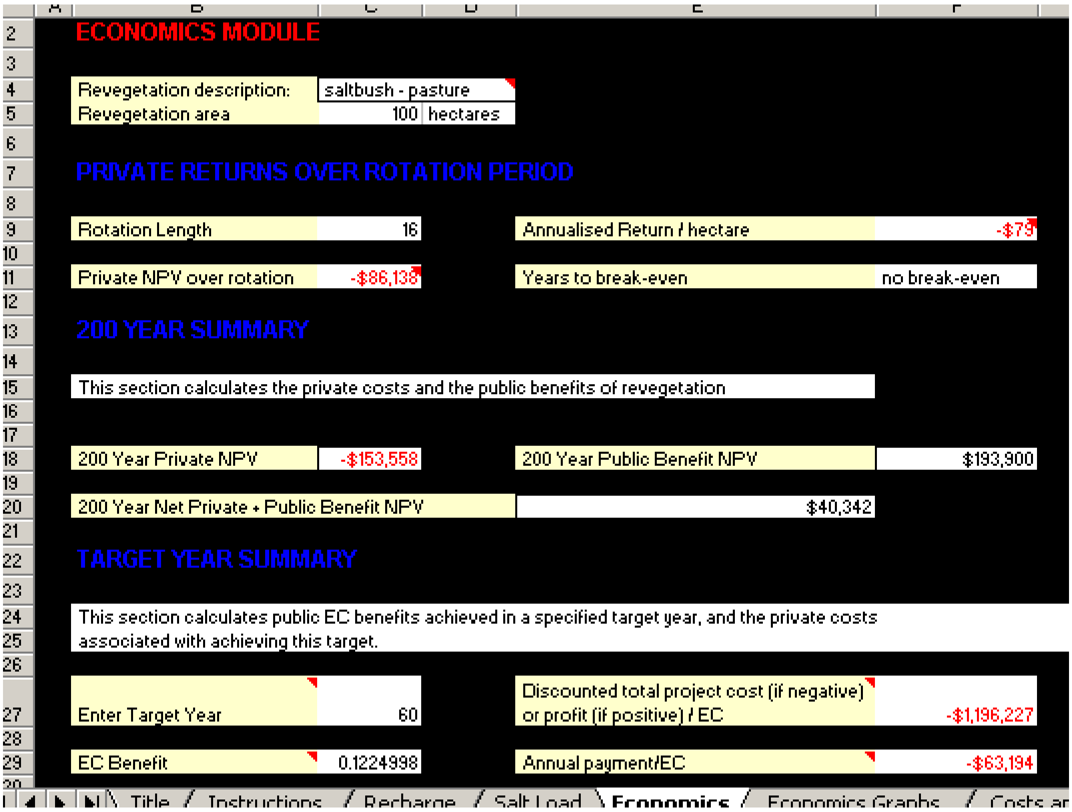


Figure 13. Economics worksheet for example 2.

To view the results describing private and public economics of saltbush to complement pasture production, tab back to the ECONOMICS worksheet (Figure 13). The section entitled PRIVATE RETURNS OVER ROTATION PERIOD shows that while saltbush as a complement to a sheep operation is expected to produce benefit, the private benefits are not expected to cover all costs, so the net present value of this option is a negative (-$86,138). On an annualised per hectare basis the option costs about $79/annum more than the next best alternative.

The 200 YEAR SUMMARY section of the ECONOMICS worksheet shows three summary measures of public and private benefits computed over a 200 year time horizon. The annual dollar value of public benefits used in computations is based on estimates of agricultural productivity losses and urban water infrastructure damages resulting from salinity (MDBC, 2000). The results in figure 13 show that the discounted value of future public benefit over a 200 time year horizon in this example is $193,900, and the discounted value of private cost is -$153,558. In this case, the NPV of public benefits exceeds the NPV of private costs, so that the net benefit is positive $40,342.

As can be seen on the public and private benefits graph on the ECONOMICS GRAPHS worksheet (Figure 14), public benefits start accruing after about 25 years.

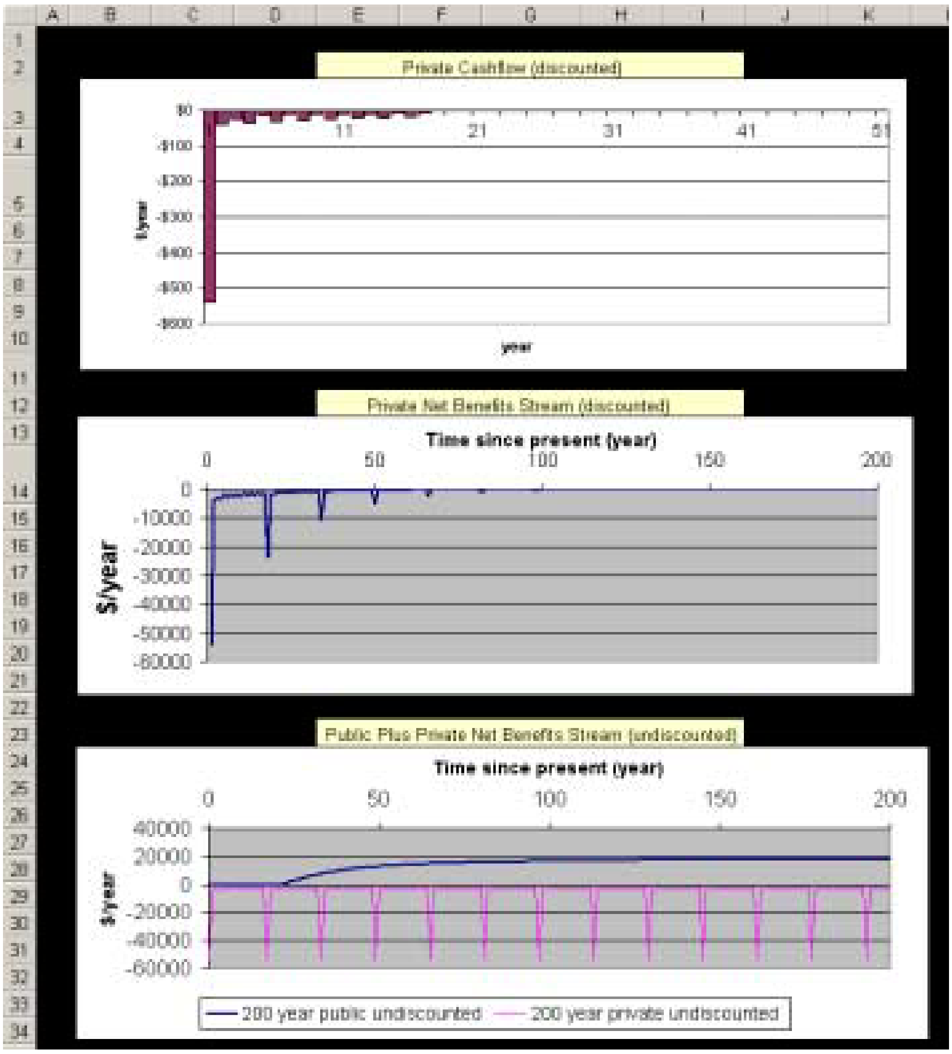


Figure 14. Economics graphs worksheet.

The TARGET YEAR SUMMARY section of the ECONOMICS worksheet calculates the discounted private cost or profit of achieving the public EC benefits that result from a revegetation option in a specified target year. For this example the user entered a target year value of 60. Results in the EC Benefit cell indicate that a 0.1225 EC unit salinity loading reduction can be expected in 60 years if a saltbush block is planted on the 100 hectare site today. The results in the Discounted total project cost or profit / EC cell indicate that discounted sum of costs per EC benefit for the revegetation option is $1,196,227.

ACKNOWLEDGEMENTS

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REFERENCES

Allison G.B., Cook P.G., Barnett S.R., Walker G.R., Jolly I.D. and Hughes M.W. (1990) Land clearance and river salinisation in the Western Murray Basin, Australia. *J. Hydrol.*, 119:1-20.

Cook P.G., Jolly I.D., Walker G.R. and Robinson N.I. (2002) From drainage to recharge to discharge: some timelags in subsurface hydrology. Dubai International Conference on Integrated Management of Water Resources in the Third Millenium. 2-6 February 2002, Dubai.

Cook P.G., Leaney F.W. and Jolly I.D. (2001) Groundwater recharge in the Mallee Region, and salinity implications for the Murray River. CSIRO Land and Water, Tech. Rep. 45/01.

Cook P.G., Walker G.R. and Jolly I.D. (1989) Spatial variability of groundwater recharge in a semiarid region. *J. Hydrol.*, 111:195-212.

Hamilton A., Bright M. and Young D. (2001) Low Rainfall Alley Farming Model Final Report. PIRSA Rural Solution, Adelaide, SA.

Jolly I.D. and Cook P.G. (2002) Time lags in salinity control: controlling recharge and halting water table rise. *Natural Resource Management*, 5(2):16-21.

Jolly I.D., Cook P.G., Allison G.B. and Hughes M.W. (1989) Simultaneous water and solute movement through an unsaturated soil following an increase in recharge. *J. Hydrol.*, 111:391-396.

Kennett-Smith A., Cook P.G. and Walker G.R. (1994) Factors affecting groundwater recharge following clearing in the South Western Murray Basin. *J. Hydrol., 154:85-105.*

Knight J.H., Gilfedder M. and Walker G.R. (2002) Impacts of irrigation and dryland development on groundwater discharge to rivers - a unit response approach to cumulative impacts analysis, CSIRO Land and Water, Technical Report 03/02, 16p.

MDBC (2000) Salinity Audit of the Murray Darling Basin: A 100-year perspective, MDBC, Canberra.

Sisson J.B. and Wierenga P.J. (1981) Spatial variability of steady-state infiltration rates as a stochastic process. Soil Sci. Soc. Am. J., 45:699-704.

Wilson J. (2001) Murray Mallee Revegetation Plan. Murray Mallee Local Action Planning Association, Murray Bridge, SA.

APPENDIX 1: DESCRIPTION OF MATHEMATICAL AND ECONOMIC MODEL

The hydrological model described in this report is based on work from numerous scientific studies, including Allison et al. (1990), Cook et al. (1989), Jolly et al. (1989), Kennett-Smith et al. (1994), Cook et al. (2001), Cook et al. (2002), Jolly and Cook (2002) and Knight et al. (2002). The economics component builds on earlier work including The Salinity Audit (MDBC, 2000), and two reports on the economics of revegetation in the Mallee (Hamilton et al., 2001; Wilson, 2001). Only a brief summary of the essential components is described here. For additional information the reader is referred to the above publications.

Recharge Module

This module calculates the recharge to the watertable that will occur in the future under no change (continued crop/pasture rotation) and following revegetation. The user enters the soil texture, and the deep drainage rate is calculated from the soil texture according to Table 1. These values are believed to be typical of the mallee region in South Australia, and are based on data in Kennett-Smith et al. (1994).

Table 1. Deep drainage rates for dryland agriculture in the mallee region, as a function of the soil texture.

Soil Texture	Deep Drainage Rate (mm/yr)
sand	30
loamy sand	20
sandy loam	15
loam	8
clay loam	4
sandy clay	2
clay	2

The user also enters the watertable depth and the time since clearing.

(i) No Change Scenario

This curve depicts the recharge to the aquifer assuming continuation of dryland agriculture, under agronomic practices typical of the mallee region.

Following clearing, the deep drainage rate increases immediately, and a pressure front is created which moves slowly down through the profile towards the watertable. The recharge rate increases only once the pressure front reaches the watertable. The velocity of the pressure front through the unsaturated zone is given by

$$V_{pf} = \frac{D}{(\theta_2 - \theta_1)} \quad (1)$$

where ***D*** is the deep drainage rate, θ_1 is the mean water content of the soil beneath native mallee vegetation (before clearing), and θ_2 is the mean soil water content in equilibrium with the new drainage rate. The depth of the pressure front at the present time is given by

$$Z_{pf} = \frac{Dt_c}{(\theta_2 - \theta_1)} \quad (2)$$

where t_c is the time since clearing.

The timelag between clearing and the increase in aquifer recharge is calculated as

$$t_L = Z_{WT}(\theta_2 - \theta_1)D^{-1} \quad (3)$$

where Z_{WT} is the watertable depth. Our model assumes a constant value for the difference between the initial and final water contents, $(\theta_2-\theta_1) = 0.06$. The value used is based on work carried out within the mallee region over a number of years (Jolly et al., 1989; Allison et al., 1990), and is appropriate for the predominantly sandy soils which comprise most of the deep unsaturated zone. In some areas, however, a heavy clay layer (Blanchetown Clay) occurs beneath the surface, and where this is the case a larger value for $(\theta_2-\theta_1)$ may be more appropriate, resulting in longer timelags. Figure 15 shows the current mapped extent of the Blanchetown Clay, and our model will overpredict the benefits of revegetation in these areas.

The recharge rate as a function of time (following the present) is thus given by

$$R_o(t) = O \qquad t < \frac{Z_{WT}(\theta_2 - \theta_1)}{D} - t_c$$

$$R_o(t) = D \qquad t \geq \frac{Z_{WT}(\theta_2 - \theta_1)}{D} - t_c \tag{4}$$

(ii) Revegetation

In areas of deep watertables, there is a timelag between revegetation, and reducing groundwater recharge. Methods for estimating this timelag have recently been discussed by Jolly and Cook (2002) and Cook et al. (2002). This model uses an approximate analytical solution, originally presented by Sisson et al. (1980) to describe redistribution of water in a uniform soil under gravity drainage. By making a unit gradient assumption, the authors show that the drainage rate below depth *z* following cessation of infiltration can be approximated by:

$$R(t) = \begin{cases} D & t \leq \dfrac{z}{A} \\ D\left(\dfrac{z}{At}\right)^{\frac{1}{1-n}} & t > \dfrac{z}{A} \end{cases} \tag{5}$$

where ***D*** is the initial steady drainage rate,

$$A = \frac{D}{n(\theta_2 - \theta_1)} \tag{6}$$

and

$$K(\theta) = \left(\frac{\theta - \theta_2}{\theta_1 - \theta_2}\right)^{1/n} \tag{7}$$

is the Brooks and Corey (1964) hydraulic conductivity – water content function over the region of interest.

Our model assumes that revegetation results in immediate drying of the soil to 5 m depth, but does not dry the soil to deeper depths. Where the pressure front is currently greater than 5 m depth, this water will continue to drain following revegetation. Recharge as a function of time is thus calculated depending on the situation being modelled.

Case 1. If $Z_{WT} < 5m$ $\quad R_1(t) = O$ (8)

(If the watertable is less than 5 m depth, revegetation results in immediate cessation of recharge.)

Case 2. If $Z_{WT} > 5m$ and $Z_{pf} > Z_{WT}$ then

$$R_1(t) = D \qquad t < \frac{Z_{WT} - 5m}{A}$$

$$= D\left(\frac{Z_{WT} - 5m}{At}\right)^{\frac{1}{1-n}} \qquad t > \frac{Z_{WT} - 5m}{A} \tag{9}$$

(The pressure front had already reached the watertable at these sites, and so the current recharge rate is equal to the drainage rate.)

Case 3. If $Z_{WT} > 5m$ and $5m < Z_{pf} < Z_{WT}$ then

$$R_1(t) = O \qquad t < \frac{Z_{WT} - Z_{PF}}{V_{pf}}$$

$$= D \qquad \frac{Z_{WT} - Z_{pf}}{V_{pf}} < t < \frac{(Z_{pf} - 5m)}{A}$$

$$= D\left(\frac{Z_{pf} - 5m}{At}\right)^{\frac{1}{1-n}} \qquad t > \frac{(Z_{pf} - 5m)}{A} \tag{10}$$

Salt Load Module

The salt load module calculates the change in load salt to the Murray River due to the change in recharge that follows revegetation.

Ultimately, the groundwater discharge to the Murray River will be reduced by an amount equal to the reduction in recharge rates multiplied by the area of revegetation. The reduction in salt load will be equal to the reduction in recharge multiplied by the area revegetated (*X*) and the groundwater salinity (*C*):

$$\Delta S(t=\infty) = CX\left(R_0(t) - R_1(t)\right) \tag{11}$$

However, there will be a time delay before the reduction in recharge results in a reduction in groundwater discharge to the Murray River. This time lag is related to the aquifer transmissivity and specific yield and the distance of the revegetation from the river. The solution for the change in groundwater discharge to the river, arising from a step change in recharge over a small area at distance *a* from the river, at early times is given by

$$Q(t) = \frac{\Delta R\, X\, a\, S^{0.5}}{2t(\pi T t)^{0.5}} \exp\left[\frac{-a^2 S}{4Tt}\right] \tag{12}$$

where *T* is the aquifer transmissivity, *S* is the specific yield, ΔR is the recharge rate, and *X* is the contributing area (Knight et al., 2002). The reduction in salt flow to the river due to revegetation is therefore given by

$$\Delta S(t) = CX \int_0^t \left(R_0(t') - R_1(t')\right) \frac{a\, S^{0.5}}{2(t-t')^{1.5}(\pi T)^{0.5}} \exp\left[\frac{-a^2 S}{4T(t-t')}\right] \; dt' \tag{13}$$

Our model uses Equation 13 to calculate the change in salt load. The model assumes a constant value for the specific yield of 0.1. The user enters the revegetation area (in hectares), the distance to the river, the aquifer transmissivity and the groundwater salinity. Figure 17 gives aquifer transmissivities for the western mallee region. This map does not represent aquifer transmissivities at each location, but rather the mean transmissivity between each location and the river. The groundwater salinity required by the model is not the groundwater salinity at the revegetation site, but is the salinity of the groundwater adjacent to the river, which will be downgradient of the site. This is shown in Figure 18.

Economic Module

The formulas underlying the three sets of economics calculations the program performs are discussed in the following sequence:

1. Private Returns Over Rotation Period

2. 200 Year Summary

3. Target Year Summary

1. Private Returns Over Rotation Period

The private NPV over the rotation period is the discounted value of all revenues less all costs summed over the rotation period entered on the ECONOMICS worksheet.

$$\text{Private NPV} = \Sigma_{t=1,T} \{(P \times Y_t) - (OC_t + EC_t + AC_t)\} / (1 + r)^t$$

where P is the expected price per unit yield, Y_t is the yield expected in each year t, OCt, ECt, ACt are the opportunity cost, establishment costs and annual costs in year t, r is the real annual interest rate and t is an index of years up to the end of the rotation (year T).

In the case of a positive private PV, annualised return per hectare is the annual payment that would be paid equivalent to the value of the net income from a rotation if all money was borrowed period T years at the annual real interest rate r. In the case of a negative private NPV, annualised return per hectare is the annual payment that an individual who borrowed the NPV amount for the rotation period T years at the annual interest rate r would have to pay. The formula for annualised return per hectare (PMT) is:

$$PMT = NPV \times r \ / \ [1 - (1 + r)]^{-T}$$

The break-even year is the first year for which the discounted sum of revenues exceeds the discounted sum of costs

$$\text{Min } t \ \{ \Sigma_{t=1,T} \ (P \times Y_t) \ / \ (1 + r)^t \ > \ \Sigma_{t=1,T} \ (OC_t + EC_t + AC_t) \} \ /(1 + r)^t \}$$

2. *200 Year Summary*

The public NPV is computed as the discounted value over 200 years of the sum of annual tonnes of salt load reduction predicted with the SALT LOAD module, ΔS_t from the revegetation times the benefit of an EC unit of salinity avoided, AS. Where AS is valued at $117,500, the mid range estimate of annual damage per EC increase at Morgan, from the MDBC 1999 Salinity Audit; and 100 tonnes per day of salt loading are assumed to cause a 25EC unit increase in salinity at Morgan. The discount rate for public benefits, *i*, is used in this calculation

$$\text{Public NPV} = \Sigma_{t=1,200} \ (AS \times \Delta S_t) \ / \ (1 + i)^t$$

The sum of private and public NPVs is calculated as the value of all private revenues less all costs discounted and summed over 200 years at the interest rate for private borrowing, plus the public benefit as calculated in the equation above

$$\text{Public + Private NPV} = \Sigma_{t=1,200} \ \{(P \times Y_t) - (OC_t + EC_t + AC_t)\} \ / \ (1 + r)^t$$

$$+ \Sigma_{t=1,200} \ (AS \times \Delta S_t) \ / \ (1 + i)^t$$

3. *Target Year Summary*

The **target year benefit**, ECB is the EC unit reduction expected in the target year. This is computed as tones of salt loading to the River avoided computed with the SALT LOAD module in target year N, S_N times ECBT = EC units per tonne (look-up on table 19).

$$ECB = ECBT \times S_N$$

The **Discounted total project cost or profits / EC**, is the discount sum of returns less costs required to attain the EC benefit by the target year. The value is calculated on a per

EC basis so that cost of revegetation can be compared to costs of other salinity mitigation options (i.e. salt interception). The formula is:

$$ECB = \Sigma_{t=1,N} \{ (P \times yield_t) - (OC_t + EC_t + AC_t) \} / (1 + r)^t$$

$$+ \Sigma_{t=1,200} (AS \times \Delta S_t) / (1 + i)^t$$

In the case of ECB, **annual payment/EC** is the annual payment that would be paid to an individual who loaned out the ECB amount N years at the annual interest rate r. In the case of a negative private ECB, **annual payment/EC** is the annual payment that an individual who borrowed the ECB for N years at the annual interest rate r would have to pay. The formula for **annual payment/EC** is:

$$PMT/EC = ECB^{*}r / [1 - (1 + r)]^{-N}$$

APPENDIX 2: MAPS

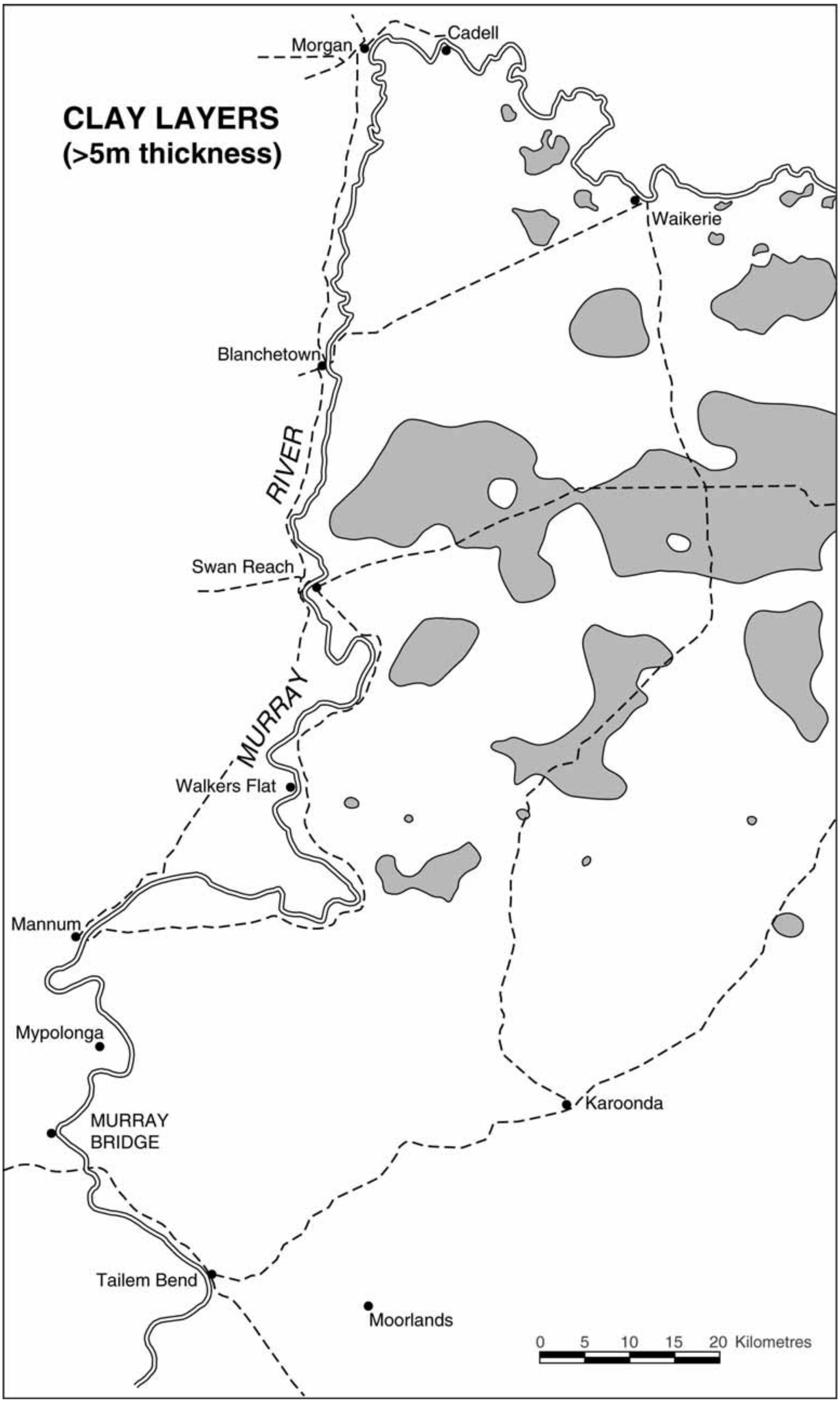

Figure 15. Presence of clay layers within the unsaturated zone.

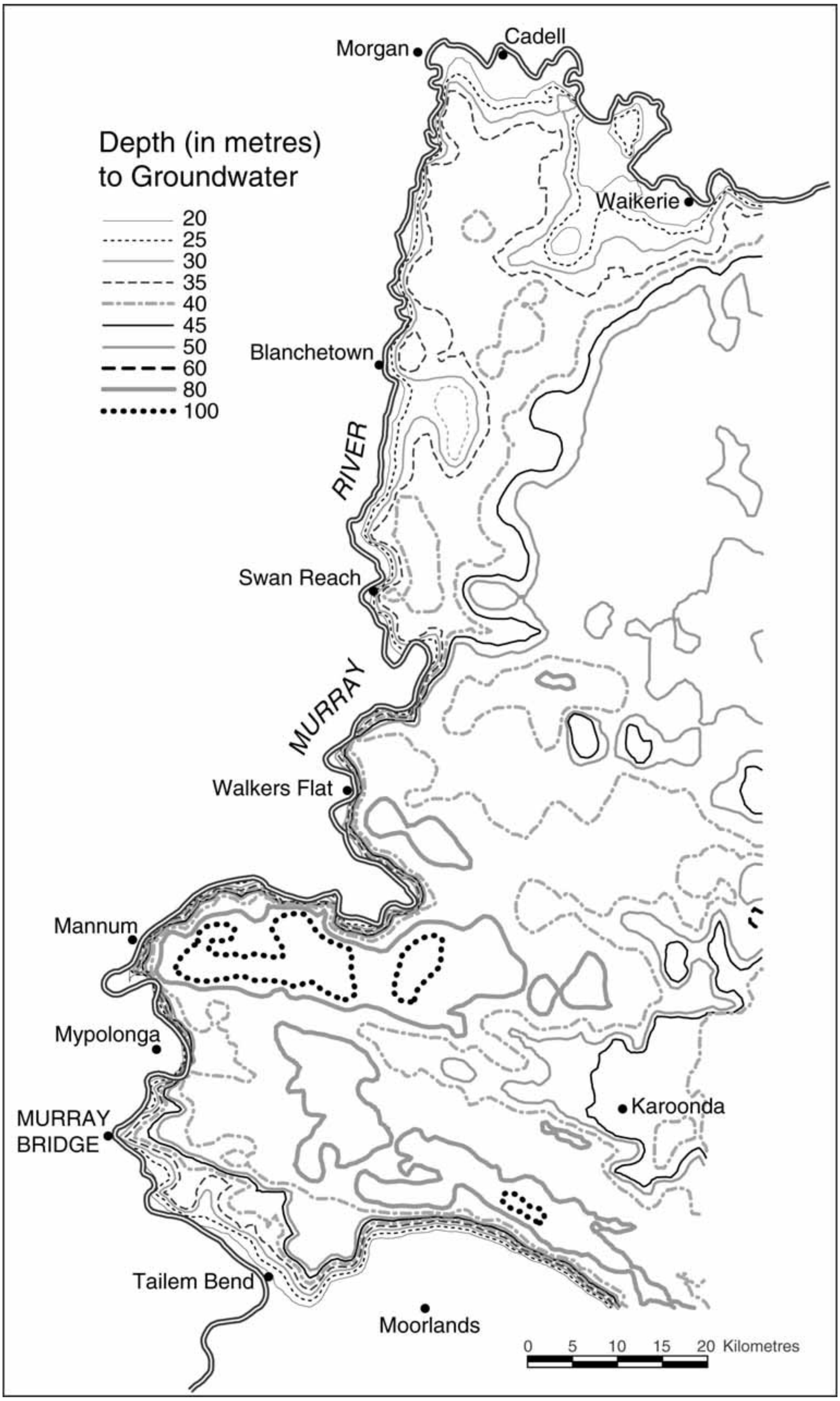

Figure 16. Depth to the watertable.

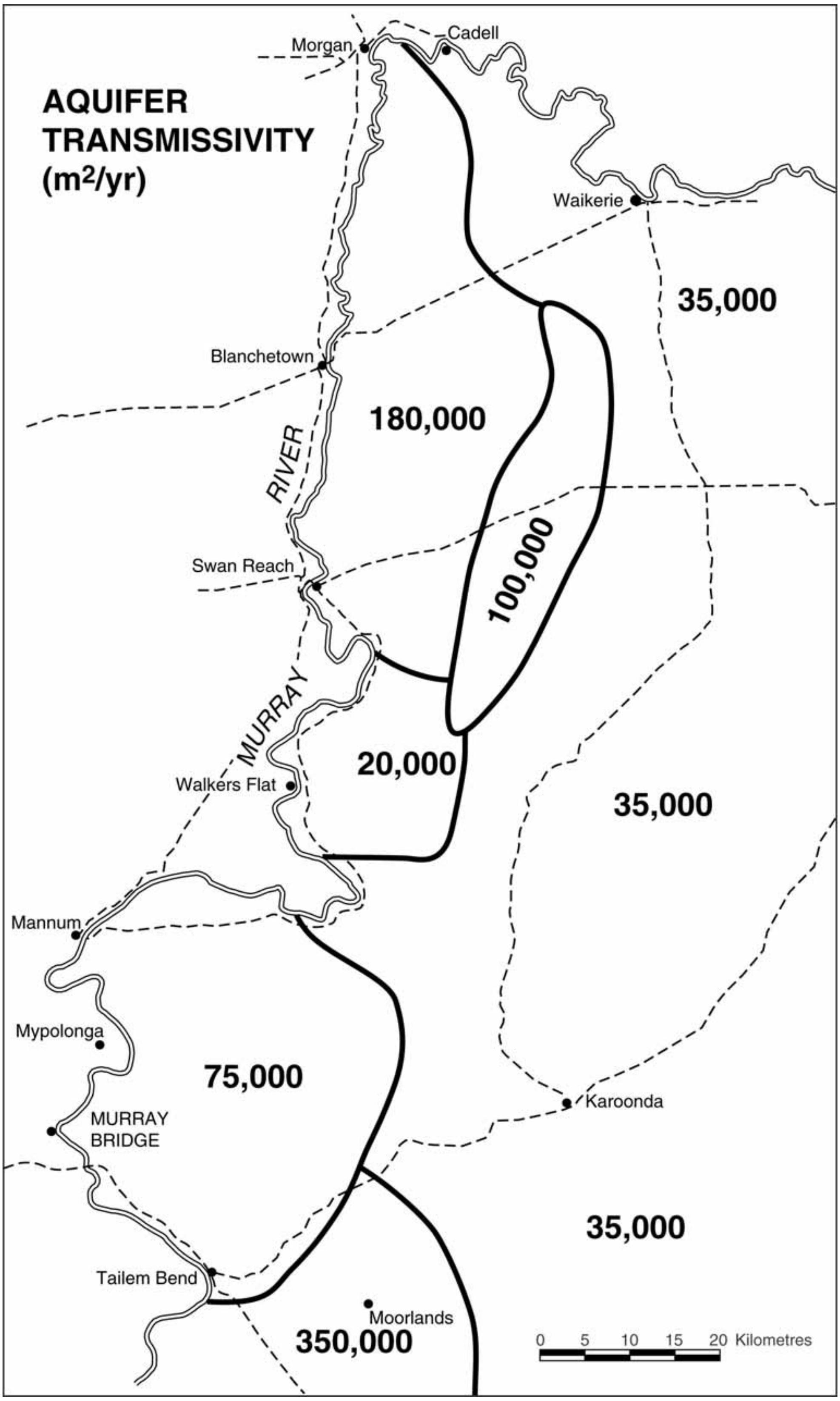

Figure 17. Aquifer transmissivity.

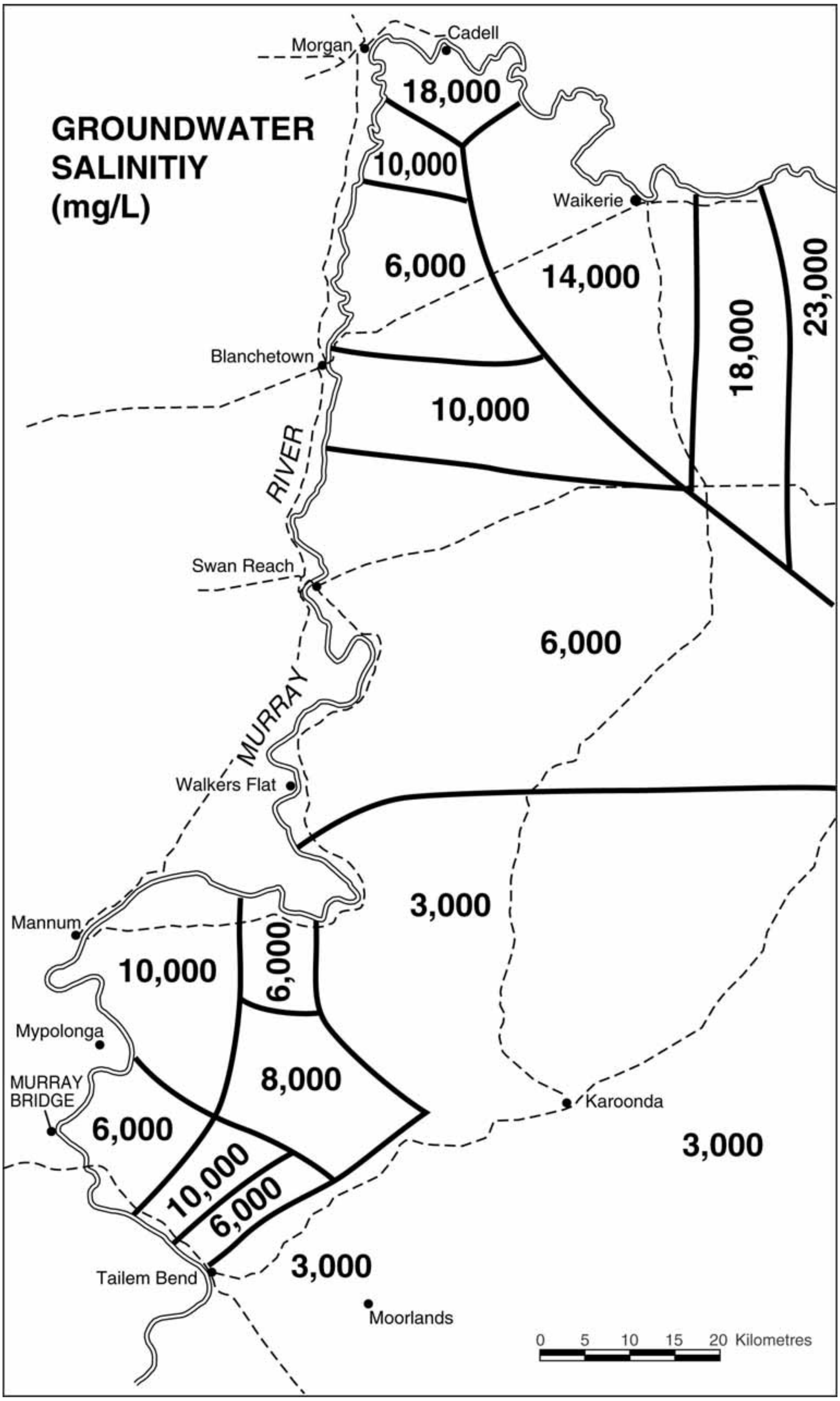

Figure 18. Groundwater salinity values.

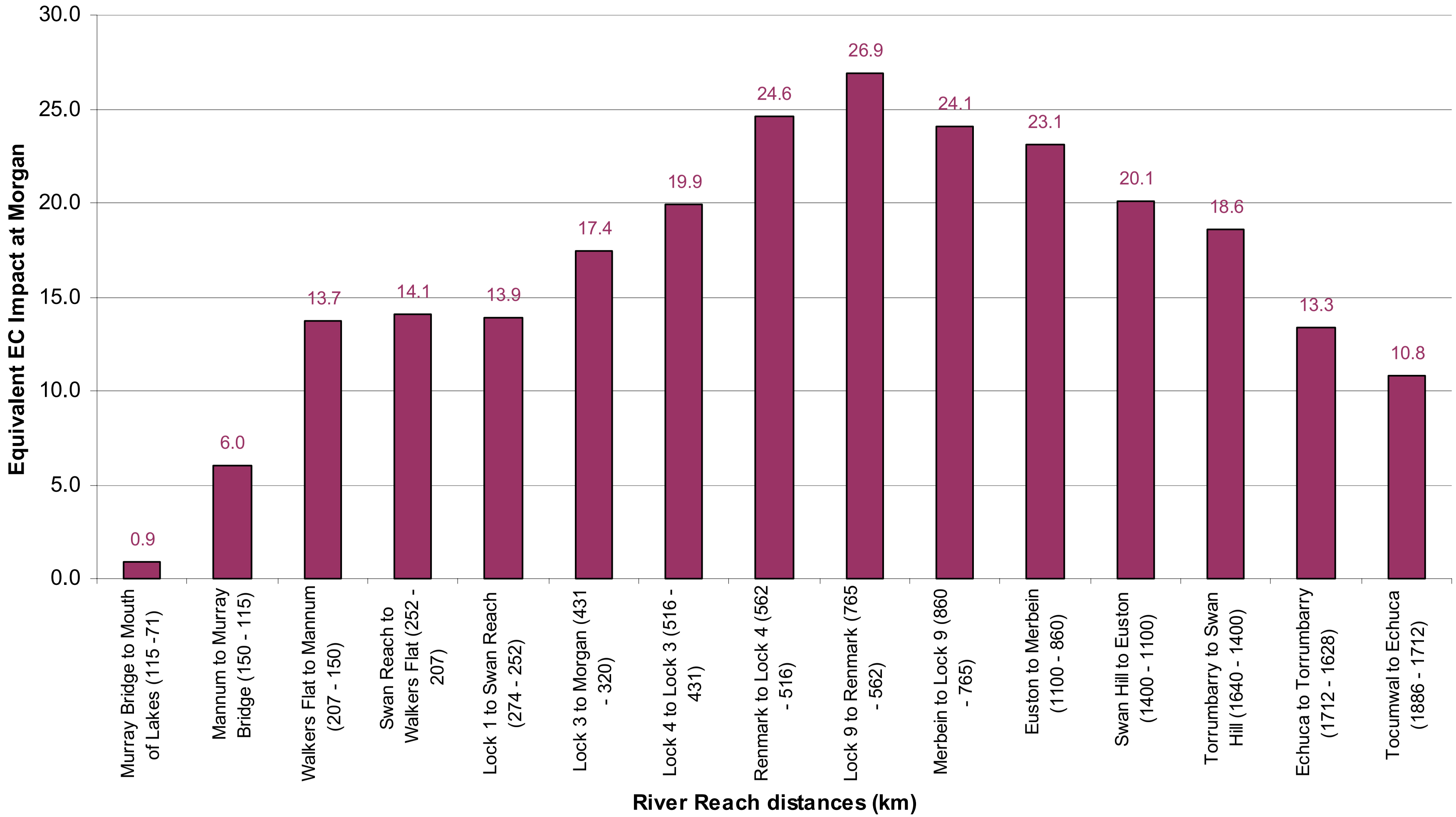

Figure 19. Salinity Cost Effect (Equivalent EC) of Salt Entering Various Reaches of the River Murray
(Modelled results assuming constant inflow of 100 tonnes/day over 1975-1985 benchmark)